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ULTRASONIC IMAGING AND AUTOMATED FLAW DETECTION SYSTEM

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An automated inspection system is described for detecting, imaging, and classifying flaws in cannon billets. The first phase of the project has produced a flaw detection system capable of triggering rapidly and reliably on flaws down to one-fourth inch in cross-section in billets up to 18 feet in length and 22 inches in diameter. This portion of the system has been optimized for low cost, high speed, simplicity, and maintainability utilizing

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20. ABSTRACT (CONT'D)

many commercially available components with a minimum use of one-of-a-kind electronic interface boards. It is a versatile, programmable stand-alone unit capable of scanning one billet every half hour. The second phase system is designed to considerably enhance the images of flaws which have been detected and located using the first phase system by providing a much larger ultrasonic array aperture and digitizing capacity. The resulting hardware is capable of both quasi-optic lens processing and digital holography.

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PART 1

INTRODUCTION

An automated flaw detection system has been designed under contract with the Benet Weapons Lab of the U.S. Army. It is a fully automated system for use in detecting internal flaws in steel cannon billets. The goal is to locate and classify potentially hazardous flaws.

An image is created by sending a wave of ultrasonic signals into the steel and timing the arrival of acoustic reflections. The signals are sent and received through a phased array crystal transducer. The information thus gathered is digitized and stored in computer memory. An image can be derived from the collected data.

The system is designed around a commercially produced ultrasonic imager sold by Searle Ultrasound. An LSI-11 microcomputer is interfaced to the imager with custom designed modules. Ultrasonic image data is loaded into memories which can be examined by the LSI-11. The LSI-11 can then make decisions about the existence of flaws in the material.

PART 2

DESCRIPTION OF HARDWARE

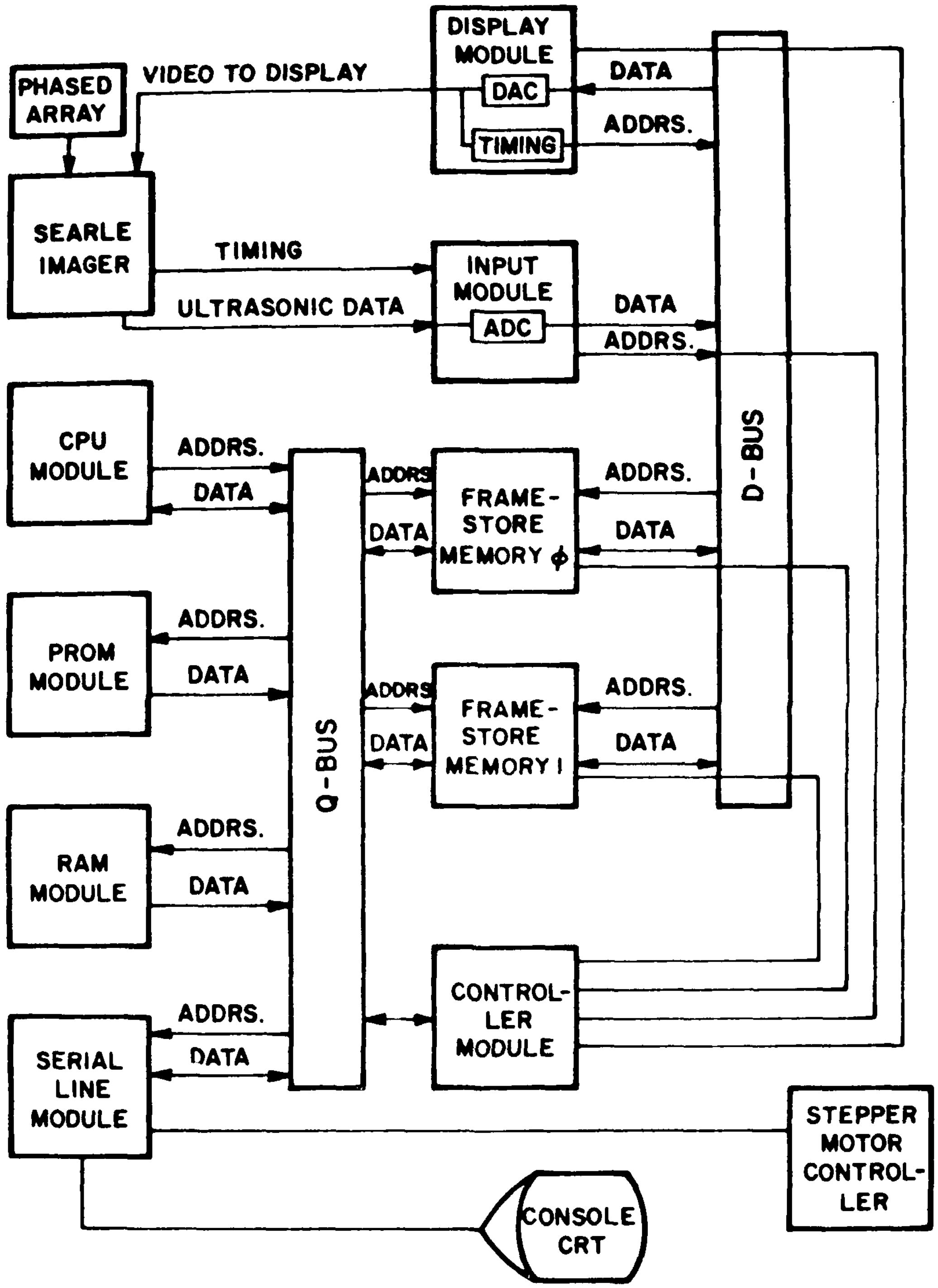
2.1 OVERVIEW OF HARDWARE

The hardware for the first phase automated ultrasonic flaw detection system is centered around a SEARLE linear phased array ultrasonic imager, an LSI-11 microcomputer, and an assortment of custom-designed electronic modules. There is also a CRT display terminal for controlling the computer, and a stepper motor with associated drive electronics to position the imager's array. Ultrasound signals from the Searle unit's array are sent to an analog to digital converter, and the digital image information is stored into one of two framestore memories. The LSI-11 microcomputer can then enhance and analyze the image numerically. Details of this part of the process are explained in the software section of this report. The image data in memory, and any annotations added by the flaw detection program, are sent to a digital to analog converter and television timing generator. The result is a standard video signal which can be fed into a video monitor such as the monitor internal to the Searle unit. The resulting image is of better quality than the images generated by the Searle unit's internal imaging electronics, with the added advantage that the image has also been analyzed by the computer for automated flaw detection.

A block diagram of the system appears in figure 1, and a photograph of the equipment is given in figure 2. The computer cabinet in the photograph consists of the Searle Ultrasonic Imager, a CRT display terminal, an LSI-11 microcomputer, and the Sigma Instruments stepping motor driver. Through the CRT terminal the operator can maintain control over each of these subassemblies to quickly and accurately detect flaws present in cannon billets.

2.2 THE SEARLE IMAGING SYSTEM

The Searle unit is a complete, self-contained, and easily maintainable linear phased array ultrasonic imaging system intended for medical applications. Its principal function is to handle the ultrasonic signal. The imager creates the signal and then sends it out to an array of piezoelectric crystals, also called the transducer array. It then switches modes and after a programmed delay will start to receive the ultrasonic reflection. This information is then used to produce an image for the video monitor on the front of the Searle unit.



SYSTEM BLOCK DIAGRAM

Figure 1

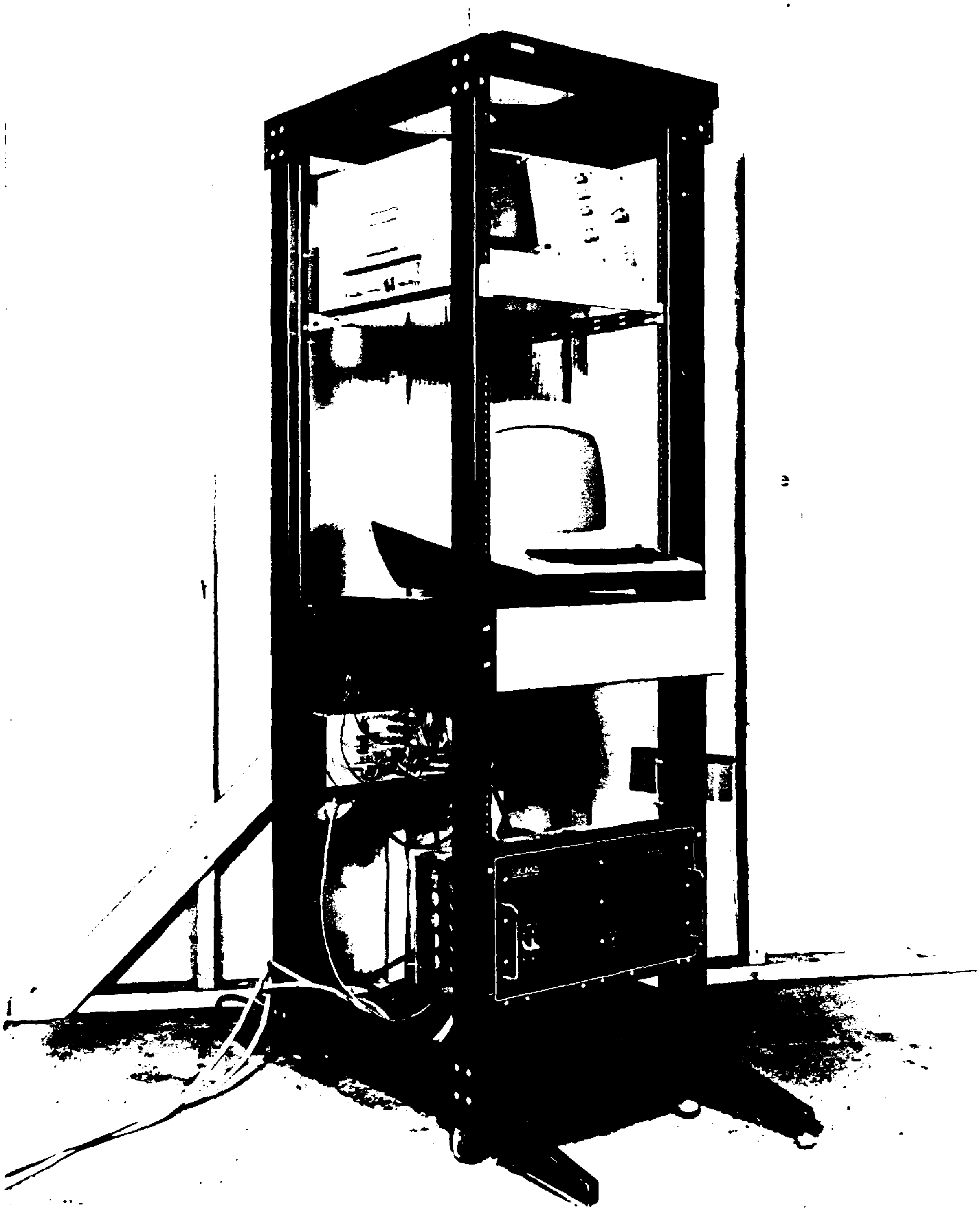


Figure 2. Photograph of System Cabinet.

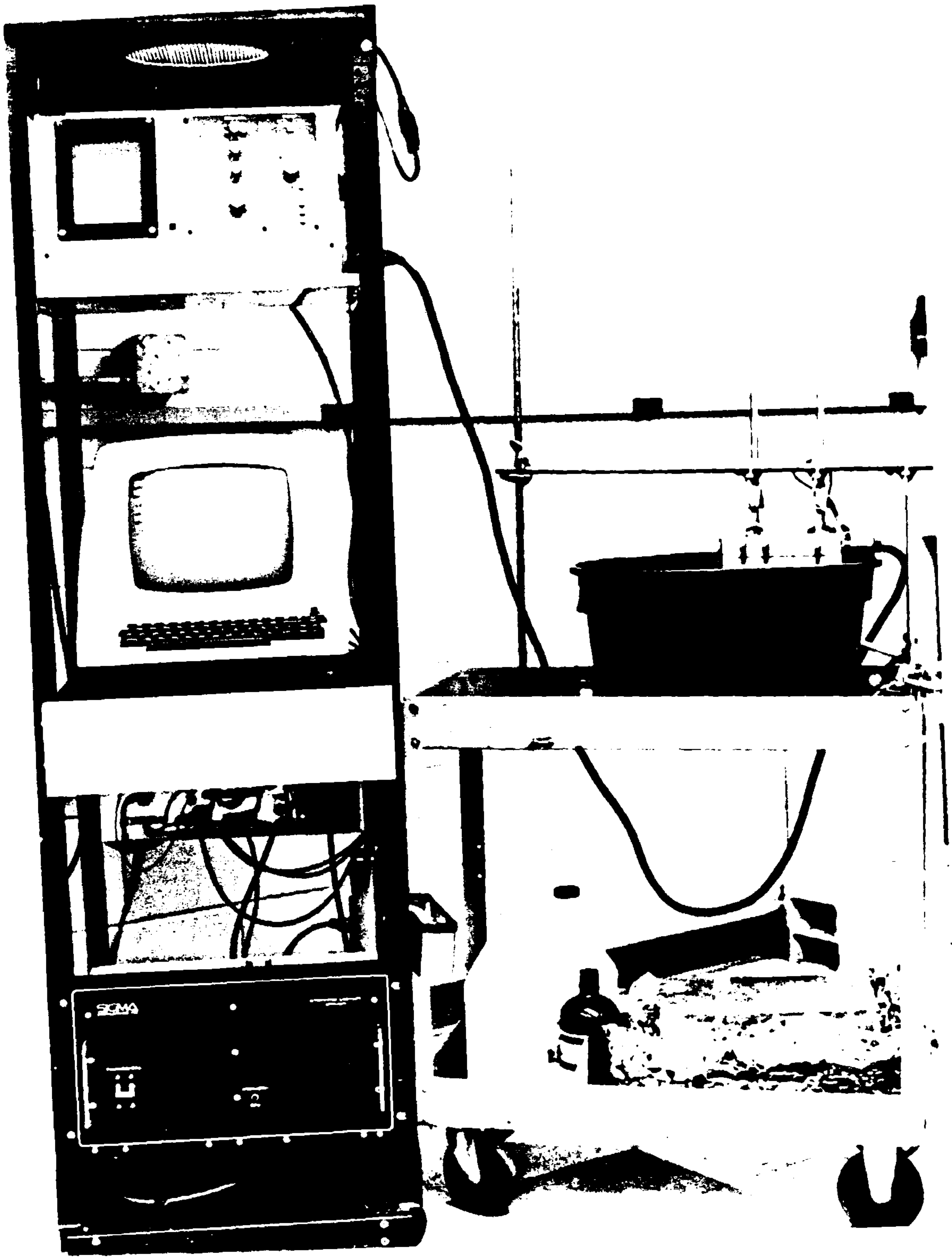


Figure 2a

The Searle unit has the capability of conditioning both the incident and the reflected signals which have been sent out and received by the transducer array. The parameters which control this conditioning could originally be set by means of several knobs on the front of the unit itself. To automate this process these knobs were disabled and the parameters were placed under computer control. In this way, once the optimum settings were experimentally determined they could be automatically programmed on power up, while still allowing for adjustments by the operator.

The Searle unit was designed to send out an ultrasonic pulse, receive its reflection, and produce an image for its video monitor without storing the image. This image can be seen when the switch on the left side of the case is in the internal video position. But when the unit is used directly on steel, the image produced is of very poor quality. The faster speed of sound in steel causes the image to be compressed in the vertical dimension, making good imaging impossible. For this reason, the ultrasonic signals from the unit are extracted and fed down to a custom designed analog to digital converter module (A/D) in the LSI-11. In digital form the image can be stored, enhanced, and analyzed for flaws. The LSI-11 then converts this information back into analog form and then sends it back up to the Searle unit for display. This analog signal is connected to the VIDEO IN terminal on the back of the Searle unit and can be seen when the switch on the left side of the case is in the external video position. An interface module has been constructed and installed in the Searle unit. It serves to buffer the analog and digital signals coming to and from the unit, as well as providing optional computer control of the front panel functions. The interface also controls the internal video monitor.

2.3 LSI-11 MICROCOMPUTER

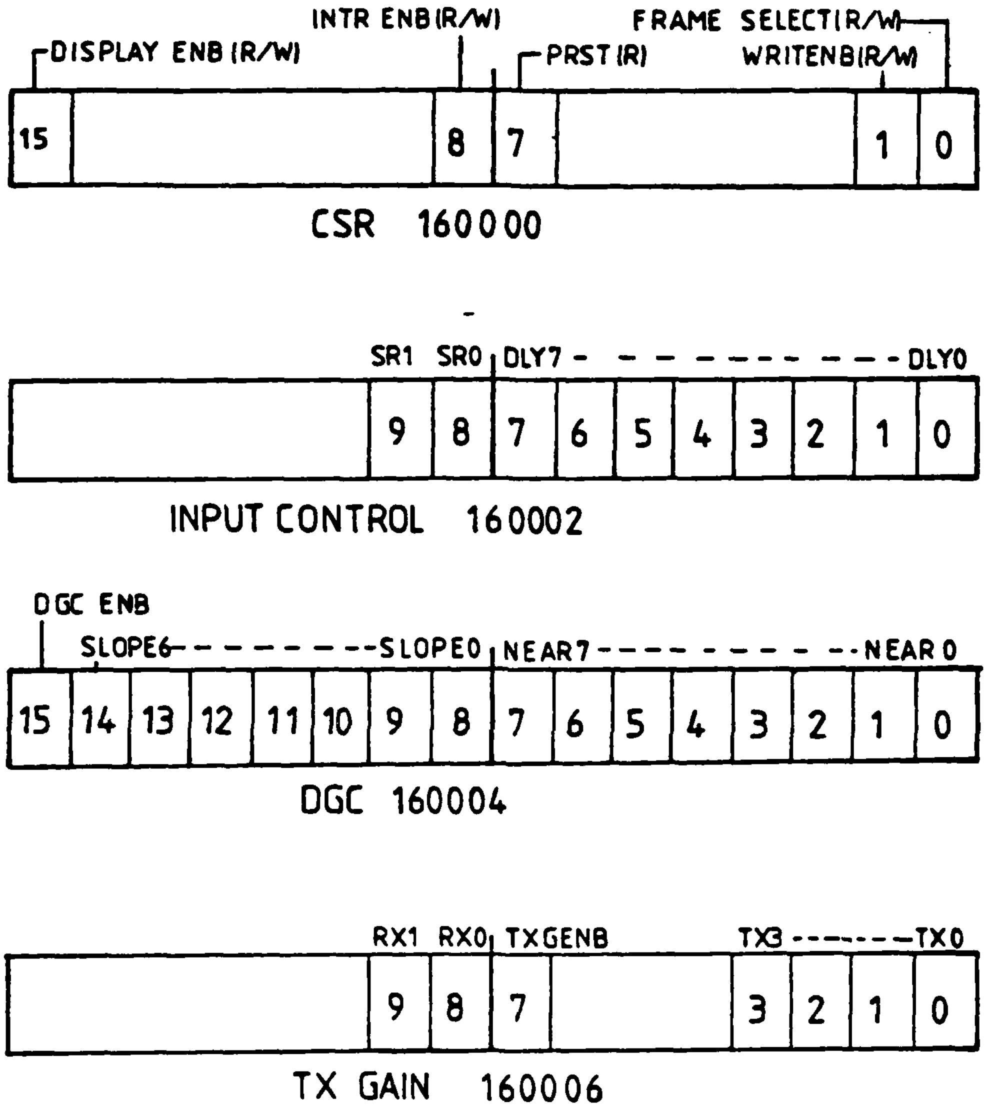
I. CUSTOM DESIGNED MODULES

The LSI-11 is reponsible for many tasks in the Flaw Detection system. These include controlling the Searle Imaging System, receiving, storing, and analyzing the data presented to it by the imaging unit, and creating a video signal which is sent back to the the Searle unit's display. The computer also controls positioning the array by means of the stepper motor driver and several switches. These switches determine the limits to which the cart is allowed to travel.

To accomplish all of these tasks several custom designed modules had to be produced that would operate in conjunction with the necessary DEC original equipment modules. There are four custom designed LSI-11 interface boards plus two others which interface to the Searle unit's internal bus, and the Sigma Instruments stepper motor driver. The four LSI-11 interface boards are described as follows:

1) CONTROLLER MODULE

This is a custom designed interface to the LSI-11 microcomputer which allows the software to have complete control of the various parts of the system. By accessing registers on this module, the program can control the acquisition of images, the gain parameters of the Searle unit, the mode of the monitor display, the handling of the framestore memories, and, in general, controlling the high speed internal data bus between the input, output, and framestore modules. A diagram of the registers and associated bit definitions is given in figure 3. Because much of the timing, amplification, display, and transmitter modules of the Searle unit are still used by the detection system, the servicing of the system is enhanced. For example, by disconnecting the interface cable from the LSI-11, the Searle unit behaves as if it was completely unmodified and could be shipped intact for repair.



CONTROLLER REGISTER DEFINITIONS

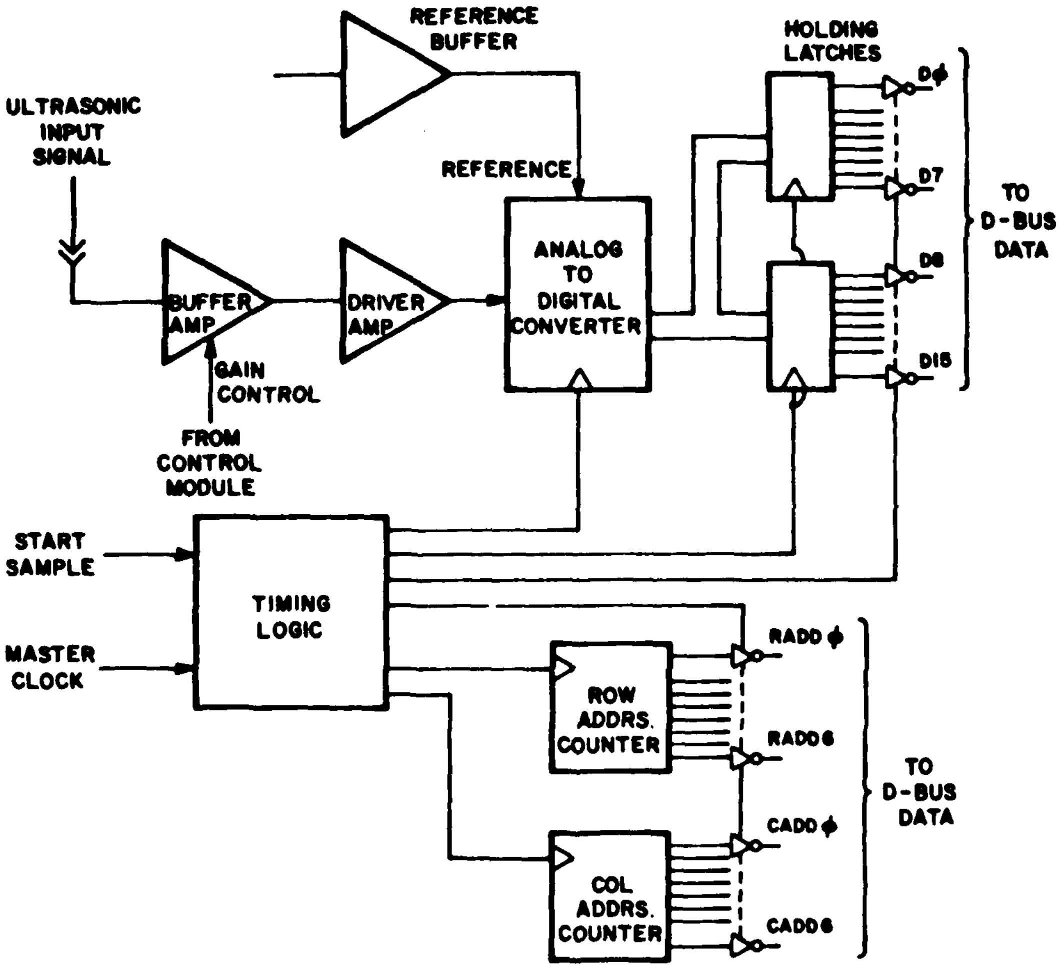
Figure 3

2) INPUT MODULE

The input module accepts the analog ultrasound image signals from the interface board in the Searle unit. An analog to digital converter on this module converts incoming image signals to digital form. Once enabled by the controller module, the input module sends the digital data out over the high speed data bus to the framestore module. Simultaneously, it generates the appropriate addresses and control signals for the memory in the framestore. Sampling rate and input signal attenuation are adjusted by software via the controller module in the LSI-11. A block diagram of the input module appears in figure 4.

3) DISPLAY MODULE

The display module is another custom designed circuit board whose function is to take the digital image data stored in the framestore and convert it into a form acceptable to a standard video monitor. Whenever the input module is not using the high speed data bus, the display module begins generating appropriate address and control signals for the framestore. Digital data read from the framestore is sent over the data bus to the display module where a digital to analog converter (D/A) creates an analog signal. Standard television synchronization is added



INPUT MODULE BLOCK DIAGRAM

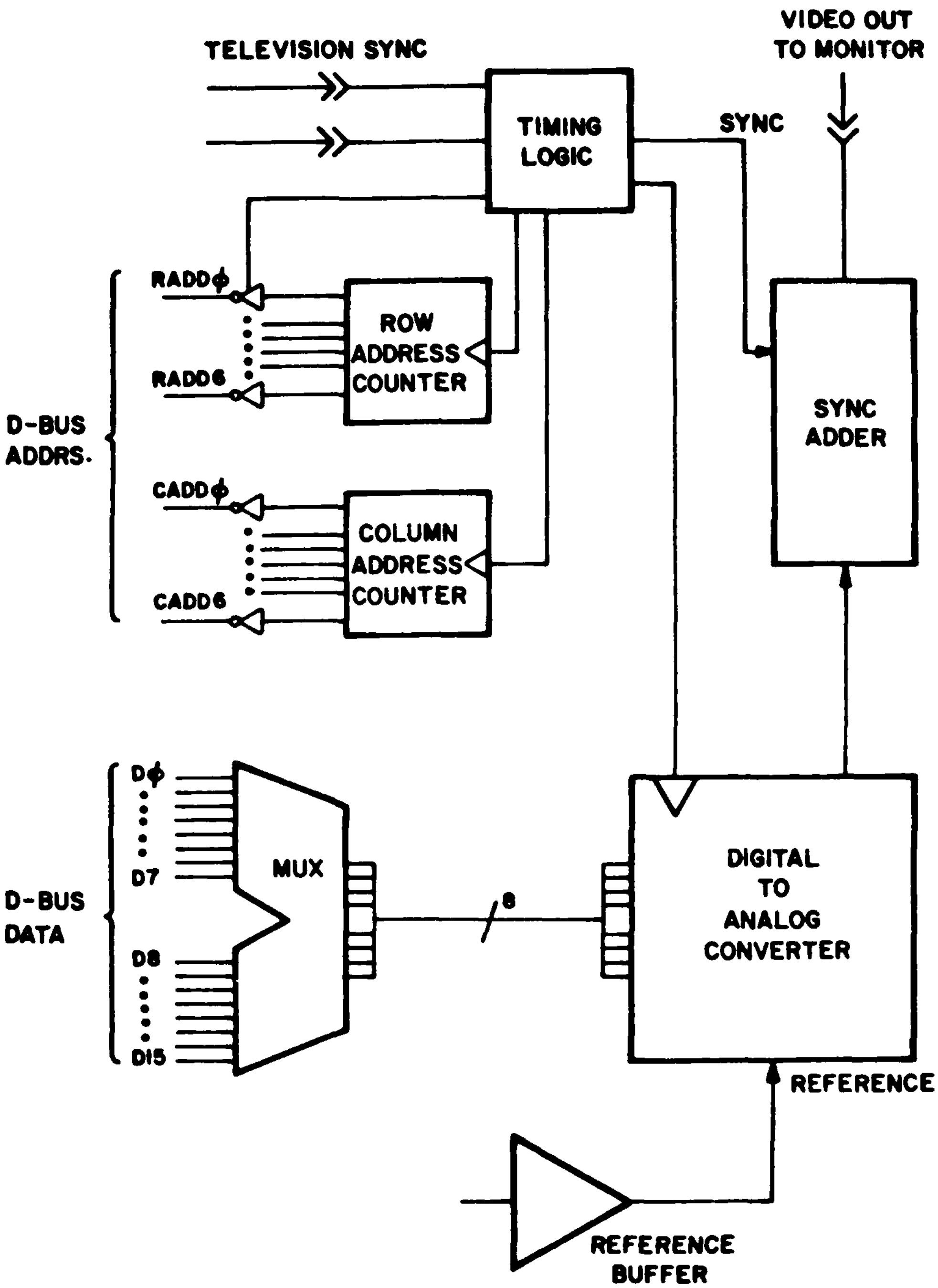
Figure 4

to the signal and the result is a video signal compatible with any television monitor. This signal is fed to the Searle unit's internal video monitor where a picture of the material under test appears. Figure 5 contains a block diagram of this module.

4) FRAMESTORE MODULES

There are two framestore modules in the system which are always in opposite modes. One framestore is enabled onto the high speed data bus (here after called D-BUS) in order to accept data from the input module or supply data to the display module. The other framestore is enabled onto the LSI-11 processor bus (Q-BUS) so that the software programs may analyze the images and look for flaws. The framestores can be alternated between the Q-BUS and the D-BUS under program control. Both framestores are always active simultaneously on different buses. In this way, image acquisition and image analysis can be overlapped in order to make the most efficient use of time. In order to implement this sharing of memory, the framestores must have access to both buses.

Memory refresh is handled by the processor on the Q-BUS while refresh cycles are not necessary on the D-BUS. The D-BUS is always active, either with data acquisition in which the input module writes into the



DISPLAY MODULE

Figure 5

framestore, or with display operation, where read cycles continuously occur. This eliminates the need for refresh cycles while a module is selected onto the D-BUS.

Photographs of the custom designed boards and the stepping motor interface board appear in figure 6.

II. STANDARD O.E.M. MODULES

In addition to the four aforementioned custom digital cards, the LSI-11 incorporates the following four highly maintainable standard modules manufactured by Digital Equipment Corporation (DEC):

1) CPU MODULE

This module is a conventional LSI-11/2 processor card supplied by DEC. The processor executes the software which controls the entire system.

2) SERIAL LINE UNIT

This module is a model DLV-11J also supplied by DEC. It is a four port serial interface card with one port connected to the CRT terminal, another connected to the stepper motor controller, and the third is wired to a standard RS-232 connector on the

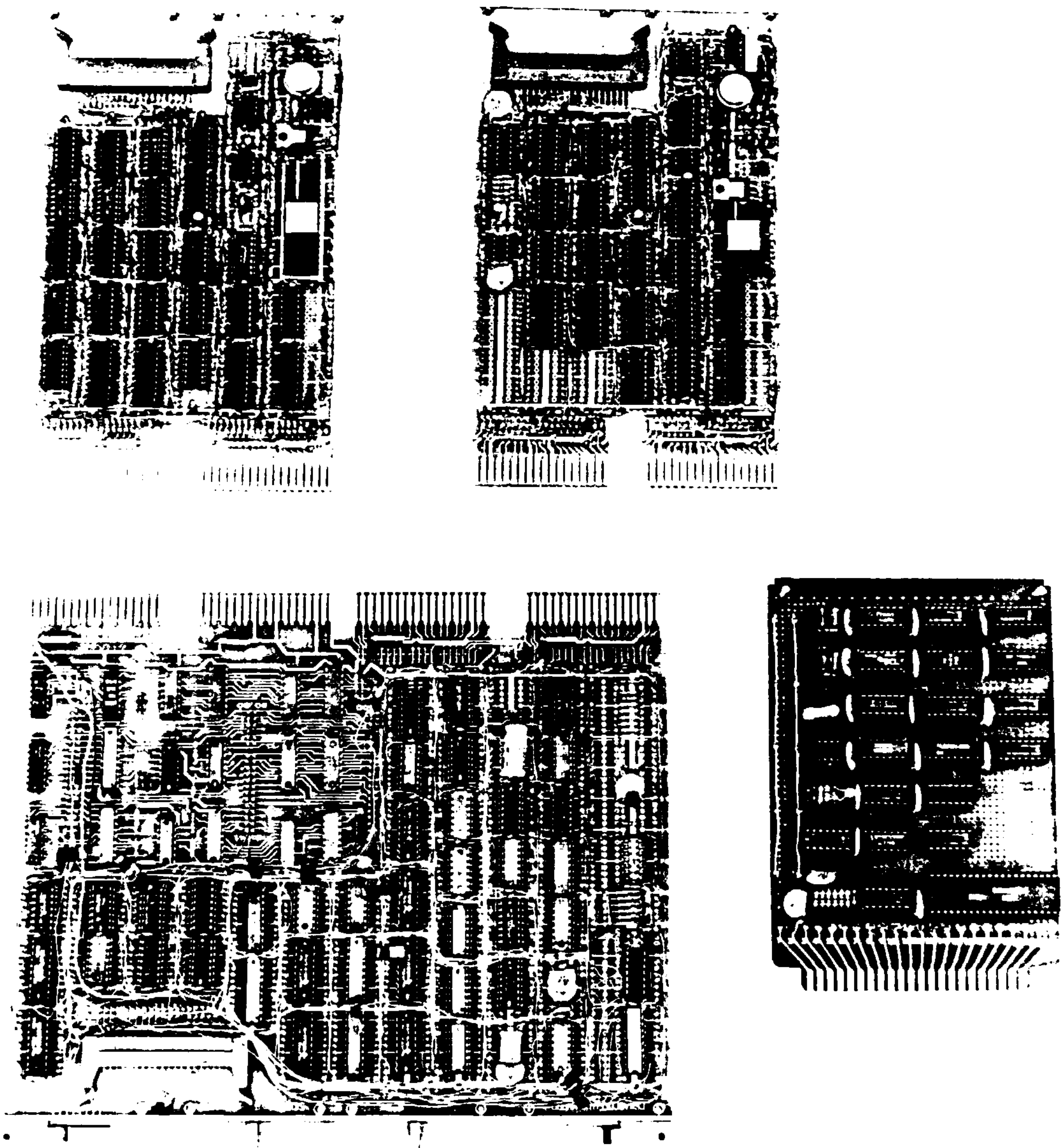


Figure 6. Photographs of Custom Modules.

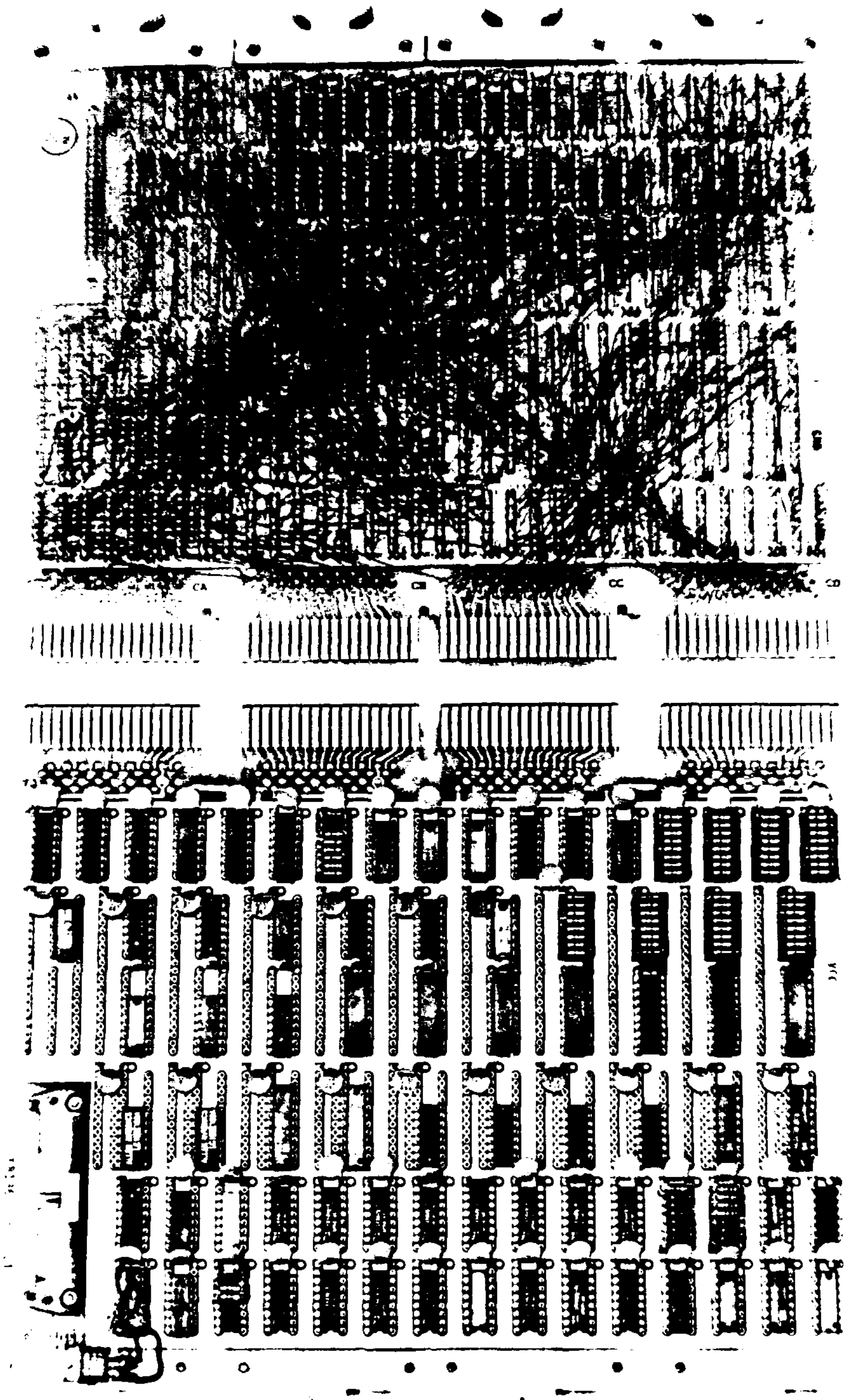


Figure 6a. Framestore Memories.

back panel of the system rack. Any other computer or system can communicate with the system through this port on the back panel. The fourth port is not used on this card. The communications standard is RS-232. The baud rate can be changed by moving jumpers on the board.

3) RAM MODULE

This is a DEC standard memory card. It is used for storage of the various variables and constants used by the software, as well as a work space for computation of various parameters of the image.

4) PROM MODULE

This is also a DEC standard memory card. It is used for storage of the software. The contents of this memory are retained, even when power is lost. This enables the system to be ready to run whenever it is turned on.

Figure 7 contains photographs of the DEC boards.

2.4 STEPPER MOTOR DRIVER

In order to position the imaging array over various parts of the sample, a Sigma Instruments stepper motor driver is used. The driver is controlled by the LSI-11 via a serial line. A custom designed interface is installed within the Sigma controller, to handle commands in the form of a direction and a stepping count. The interface then supplies a series of pulses to the Sigma stepper driver to move the motor a specified amount. When the motion is complete, the interface sets a ready flag to notify the LSI-11.

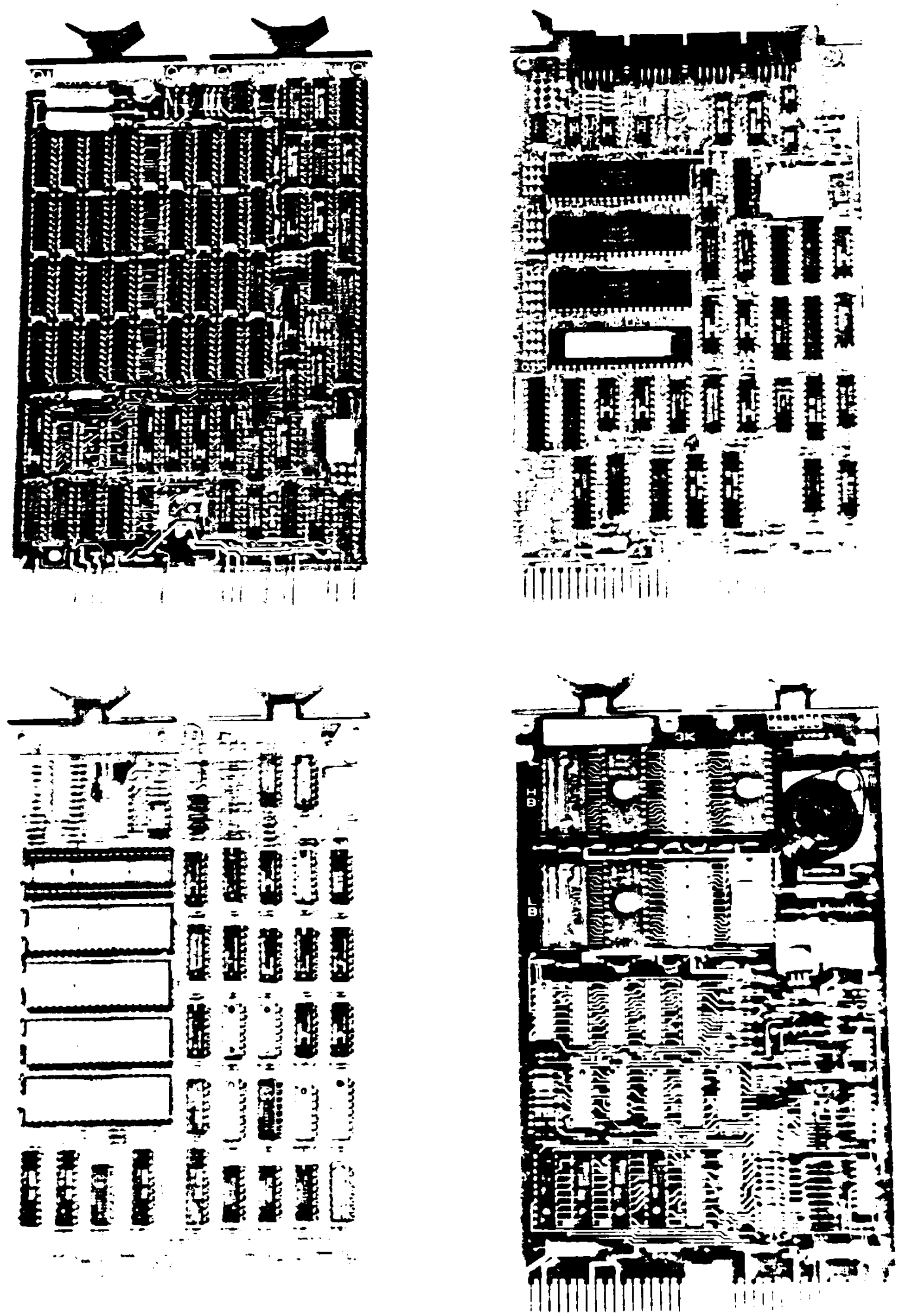


Figure 7. Photographs of DEC Modules.

PART 3

SYSTEM SOFTWARE

3.1 SOFTWARE MOTIVATION

The software for the system is permanently stored on programmable read-only memory chips mounted on the DEC PROM module. These programs are available to the user when the front panel switch is in the START position on power-up.

This is very important. If the front panel switch is not in the START position when power is turned on, the software will not be readily available to the operator.

The bulk of the software is the flaw detection algorithm. This algorithm has as its primary goal the rapid detection of any flaw within the frame. A flaw is represented by a high intensity reflection within the image of the steel. This reflection is caused by the impedance mismatch associated with a flaw or fracture. The change in density at the boundary causes part of the ultrasound wave to be passed through it and the rest of the wave to be reflected back from it. Because the change in density between steel and air is so great, most of the wave will be reflected back from the boundary.

These reflections, however, cannot be used as the primary feature on which the detection rests. Time is a limitation here. There are over 32,000 pixels in each image. Real time operations require the search to proceed at 1/30 second per frame. A real time search through this large array would involve much more time than is available.

Also, the detection of these high intensity reflections depends upon the orientation and characteristics of the flaw. If the flaw is at an angle with respect to the transducer array, the reflections may be scattered instead of reflected directly back at the imager. In this case the flaw is practically invisible to the imager.

Any flaw, without regard to its orientation or shape, will deflect some of the energy sent at it. This is used to advantage in the flaw detection algorithm.

All billets possess a smooth bore at the center. Because of this, in each image there will be reflections from the outer and inner walls of the billet. When an internal flaw or fracture dissipates some of the energy directed at it, there is a corresponding decrease in the amount of energy returned from the inner bore surface of the billet. Thus a flaw casts a shadow in ultrasound on the inner bore surface. By inspecting the reflections from this surface, the presence or absence of a flaw can be determined by detecting these shadows. Confirmation of the flaw's existence can be made if its surface features are so oriented as to reflect directly back into the array aperture.

3.2 FLAW DETECTION ALGORITHM

The initial task of the program is to find the inner wall. The image of the wall is blurred by the long depth of focus and the resolution of the aperture in both length and depth directions. The task of finding the wall is accomplished by a fast scan at each recorded depth. The wall will be indicated by a line of high intensity reflection oriented horizontally. The program must have centered the image on the framestore through the internally programmable delay. If the inner and outer surfaces cannot be identified, due to misalignment or insufficient reflection, the program traps back to command mode.

Once the program has identified the inner surface, the testing for regions of diminution, or shadows, begins. The image of the backwall is blurred in depth and length. An averaged vector is created from the sampled backwall. At each sample point, the program sums over the inner bore surface in the depth dimension. This gives a picture of the total energy reflected from the wall.

The blurring of the image in depth and length causes a corresponding blurring of the intensities as seen by the program scanning along the image of the wall. To reduce this effect, the program looks at groups of pixels at once. Averaging in this way does tend to filter the true data. However, if the image is clear enough in the length dimension, this method will preserve the shadows while reducing the inherent blurriness of the image.

These intensities thus extracted from the image are compared to a sample of the backwall with no flaws present. Two criteria are used in judging a flaw: a diminution in reflected intensity below the established threshold, and a minimum width for the shadow. Regions satisfying these criteria have their boundaries logged in an array.

The areas of the image above the shadow are then searched for possible secondary confirmation from the reflections from the flaw or fracture itself. The result of the search for each frame is reported out, and any flaws discovered are marked for display. Occasionally such confirmation is not possible due to the orientation of the flaw. Distinction of two close targets may not be possible, but the flawed region containing both targets can be identified.

Figure 8 contains a flow chart of this algorithm.

3.3 THRESHOLDS

An important aspect of the algorithm in this system is the thresholds used in the various tests. The values used are affected by several factors, including the transmission gain, the size and composition of the sample, and the focusing of the array. These thresholds must be linked to the values obtained by the image, but must also reflect the choices of the operator. The best approach in this algorithm is to allow a greater possibility for false identification than for false rejection with respect to each pixel. This is optimal because the minimum width criterion can then be used to lower the false indentification error.

The best approach in a real time system for setting accurate thresholds involves sampling the unbiased image at the beginning of each run. The threshold for shadow detection can then be derived from the intensity function along the unbiased inner bore surface.

FLOW CHART OF FLAW DETECTION ALGORITHM

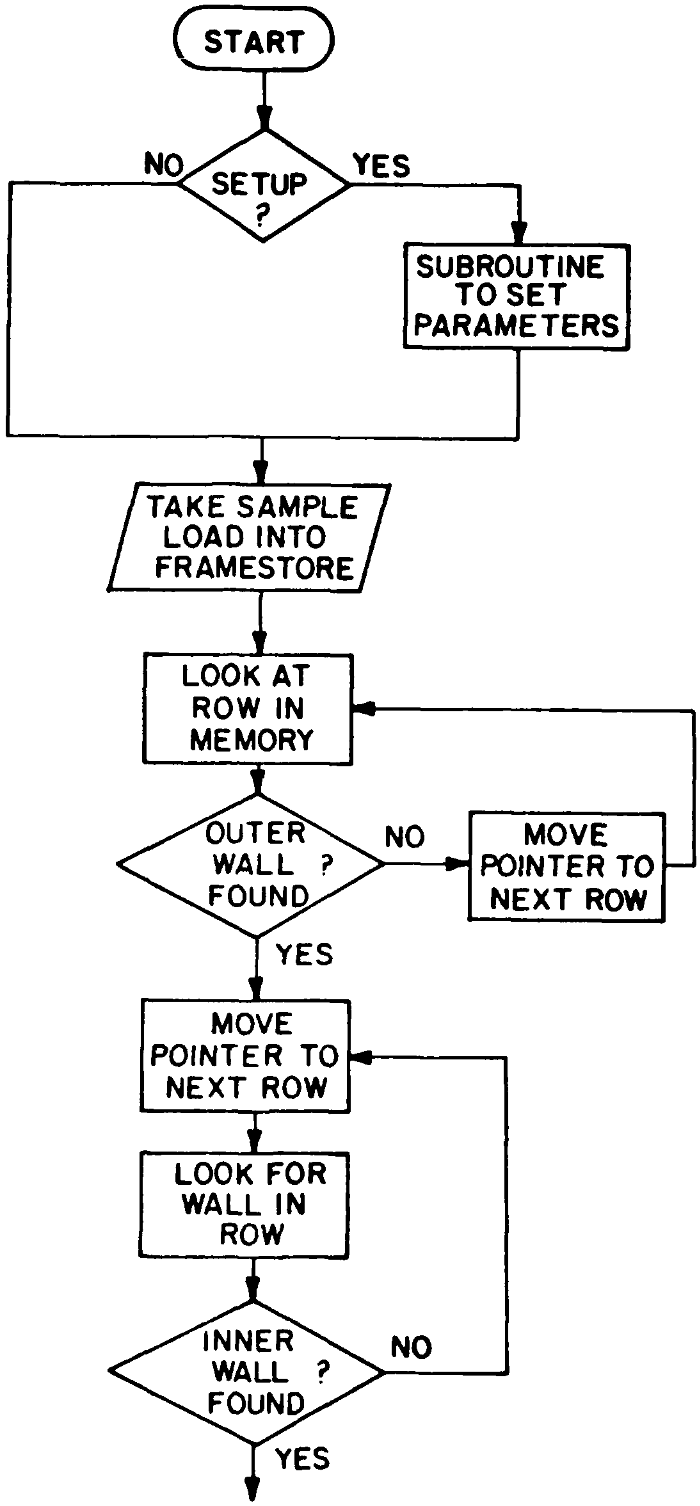


Figure 8a

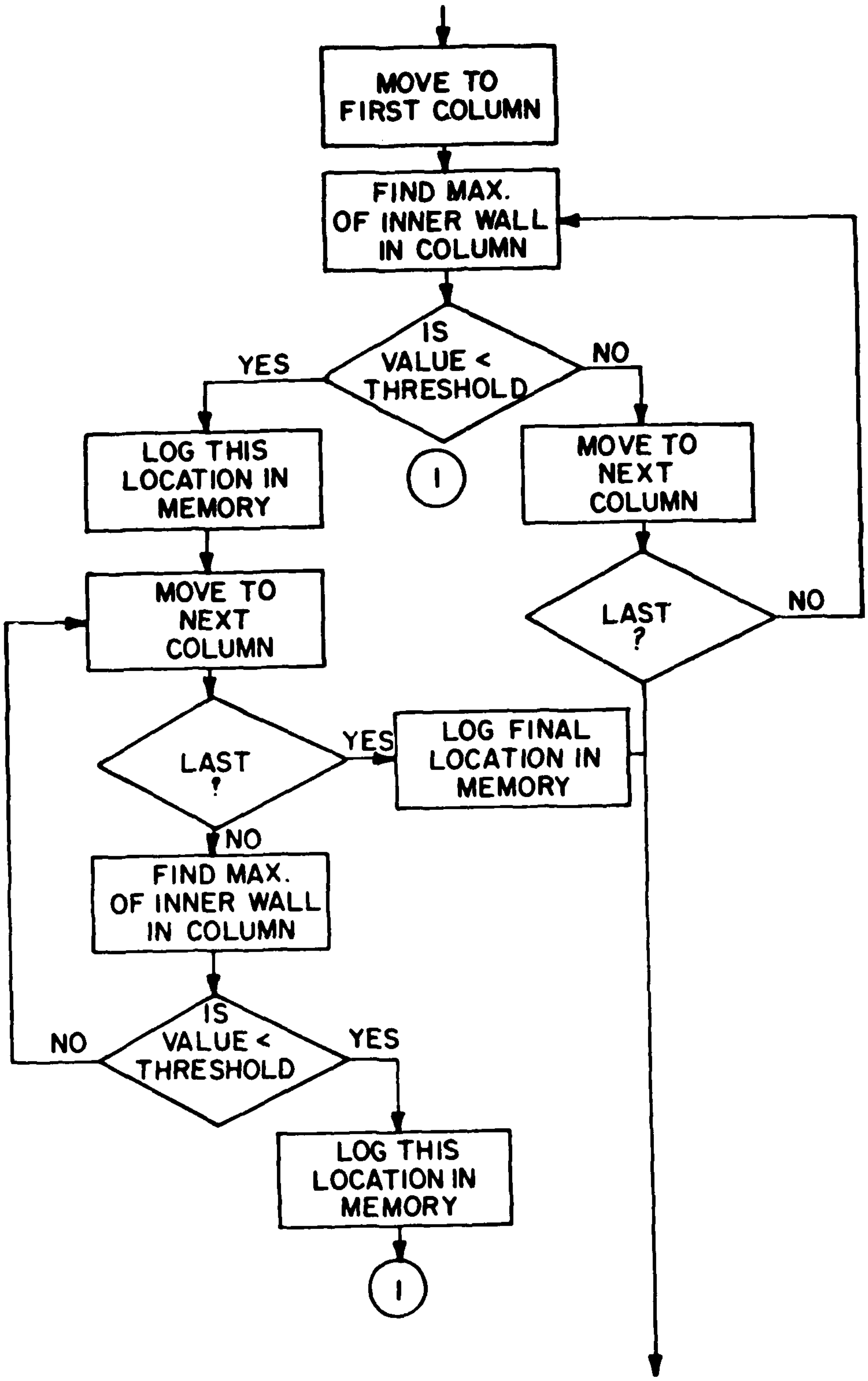
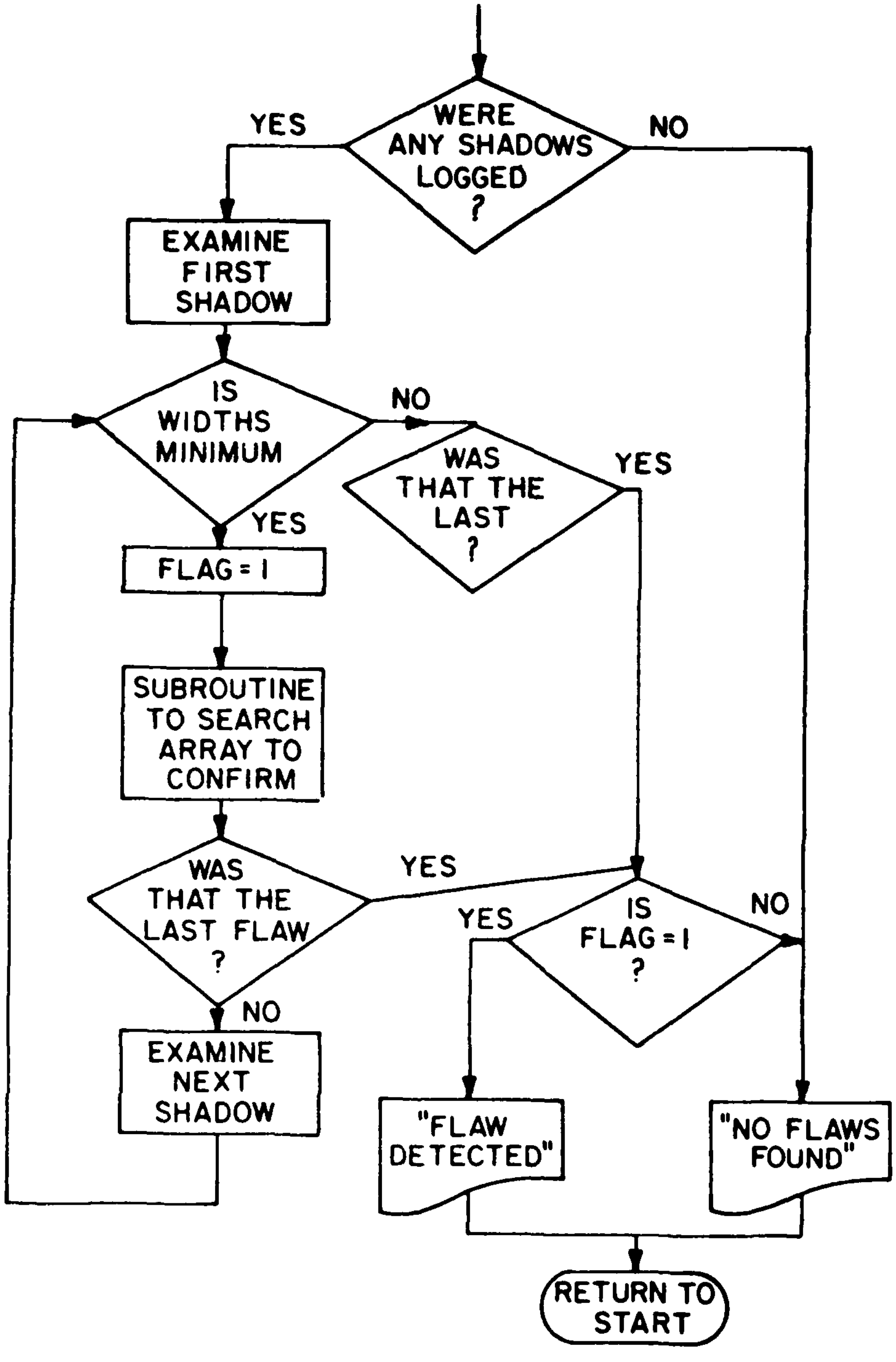

MOVE TO FIRST COLUMN
FIND MAX. OF INNER WALL IN COLUMN
IS VALUE < THRESHOLD
YES
NO
LOG THIS LOCATION IN MEMORY
1
MOVE TO NEXT COLUMN
MOVE TO NEXT COLUMN
LAST ?
NO
LAST ?
YES
LOG FINAL LOCATION IN MEMORY
NO
FIND MAX. OF INNER WALL IN COLUMN
IS VALUE < THRESHOLD
NO
YES
LOG THIS LOCATION IN MEMORY
1

Figure 8b



WERE ANY SHADOWS LOGGED ?
YES
NO
EXAMINE FIRST SHADOW
IS WIDTHS MINIMUM
NO
YES
WAS THAT THE LAST ?
YES
FLAG = I
SUBROUTINE TO SEARCH ARRAY TO CONFIRM
WAS THAT THE LAST FLAW ?
YES
NO
IS FLAG = I ?
YES
NO
EXAMINE NEXT SHADOW
"FLAW DETECTED"
"NO FLAWS FOUND"
RETURN TO START

Figure 8c

3.4 MEMORY ALLOCATION

A diagram which describes how memory is allocated in the LSI-11 microcomputer can be found in figure 9. The system software which has already been mentioned is mapped into memory locations 0 through 17777. All addresses are in octal. These are the 4k of addresses the DEC PROM module has been set up to recognize.

The DEC RAM module is configured to recognize memory locations 20000 through 57777. Memory locations 20000 through 27777 are assigned as the program stack. Locations 30000 through 40000 are used for storing the values of variables and other partial results created by the software. The first task the software has when power is turned on to the computer is to copy all of the codes from the Read Only Memory chips into the Random Access Memory chips. These read-write memory chips recognize addresses 40000 through 60000 and it is from these addresses that the processor fetches instructions for execution.

The framestore which is connected to the LSI-11 processor bus recognizes addresses 60000 through 157777. Which framestore is actually connected to the Q-Bus is determined by one bit in memory location 160000. This register which is addressed as 160000 and three others which have addresses through 160006 are

```
      0  !-----------------------!
         !                       !
         !                       !
         !    RAM: CODE          !
         !                       !
         !                       !
 20 000  !-----------------------!
         !                       !
         !    RAM: STACK         !
         !                       !
 30 000  !-----------------------!
         !                       !
         !    RAM: WORKSPACE     !
         !                       !
 40 000  !-----------------------!
         !                       !
         !                       !
         !   PROM: CODE          !
         !                       !
         !                       !
 60 000  !-----------------------!
         !                       !
         !                       !
         !/                      !/
        //    FRAMESTORE        /
       / /                     / /
        /                       /
       /!                      /!
         !                       !
160 000  !-----------------------!  --!
         !  CONTROLLER           !    !
160 007  !-----------------------!    !   D
         !                       !    !   E
         !                       !    !   V
176 500  !-----------------------!    !   I
         !  STEPPER MOTOR        !    !   C
176 507  !-----------------------!    !   E
         !                       !    !
         !                       !    !   R
176 560  !-----------------------!    !   E
         ! CRT TERMINAL          !    !   G
176 567  !-----------------------!    !   S
         !                       !    !
         !                       !    !
         !                       !    !
177 777  !-----------------------!  --!
```

MEMORY ALLOCATION MAP

FIGURE 9

physically located on the controller board and have been discussed earlier. There are four more sets of registers for each port of the DEC Serial Line Unit. Each port has a transmit and receive data buffer, plus a transmit and receive status register. These four device registers for any port are assigned to contiguous memory locations. The stepper motor device registers are at memory locations 176500-176506 and the CRT terminal device registers are at 177560-177566.

PART 4

MECHANICAL ASSEMBLY

4.1 TRANSDUCER CART ASSEMBLY

The mechanical assembly is essentially a linear tracking system. The structure consists of two main subassemblies: the transducer cart assembly and the main support assembly.

The main structure of the cart is built around a pair of inverted A-frames. These frames, in addition to all the metal structures of the mechanical assembly, are constructed out of aluminum alloy. This was chosen because of aluminum's high strength to weight characteristic and its relative ease in machining. The device that holds the transducer in the cart consists of three plates: the clamping plate, the holding plate, and the nose plate. A photograph of the Transducer Cart Assembly appears in figure 10, and a mechanical drawing appears in figure 11. The nose plate is positioned at the bottom of the cart assembly. Besides being a main structural support for the overall A-frame, the neoprene cushioned slot in the center of the plate keeps the transducer vertically aligned. The holding and clamping plates are responsible for

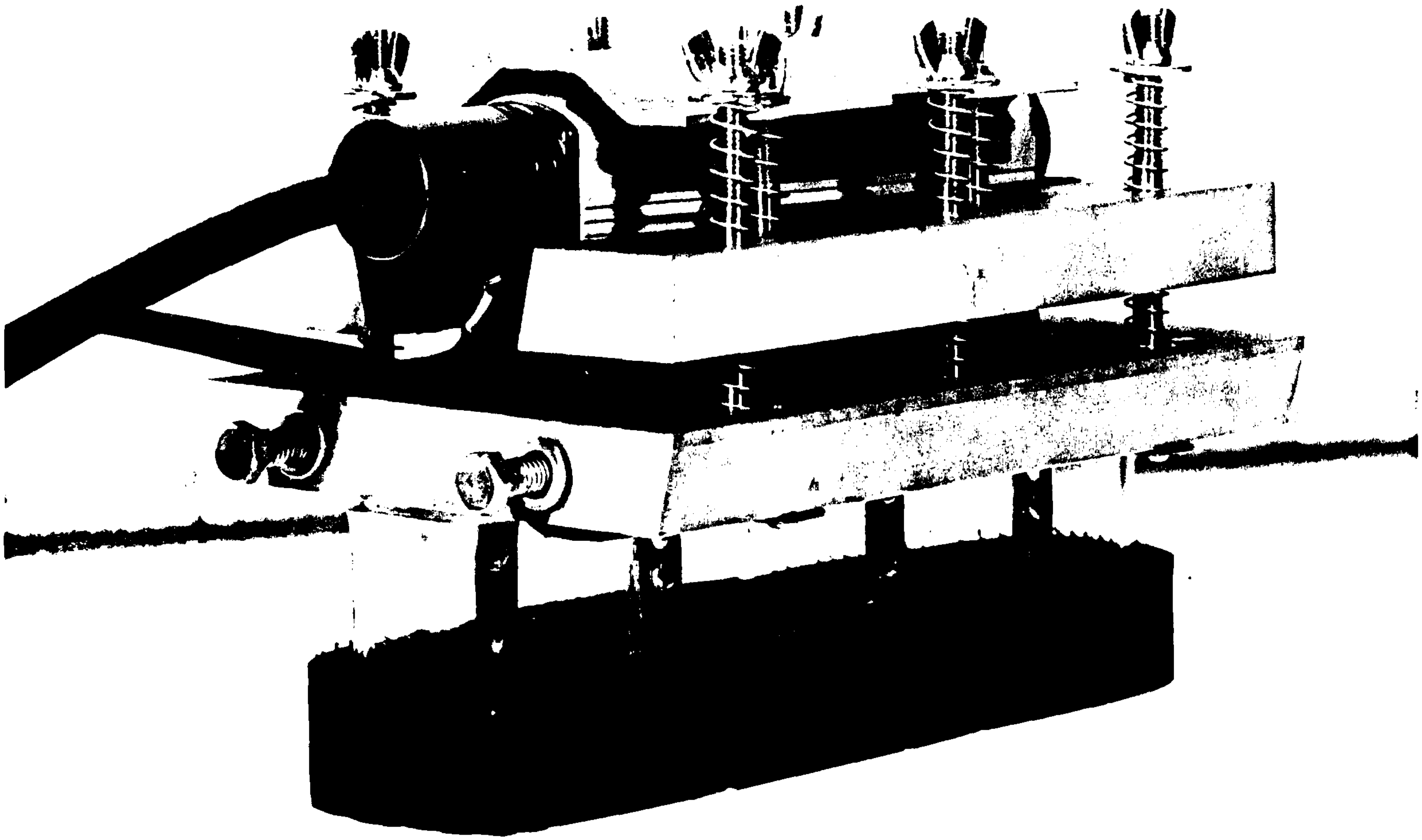


Figure 10. Transducer Cart.

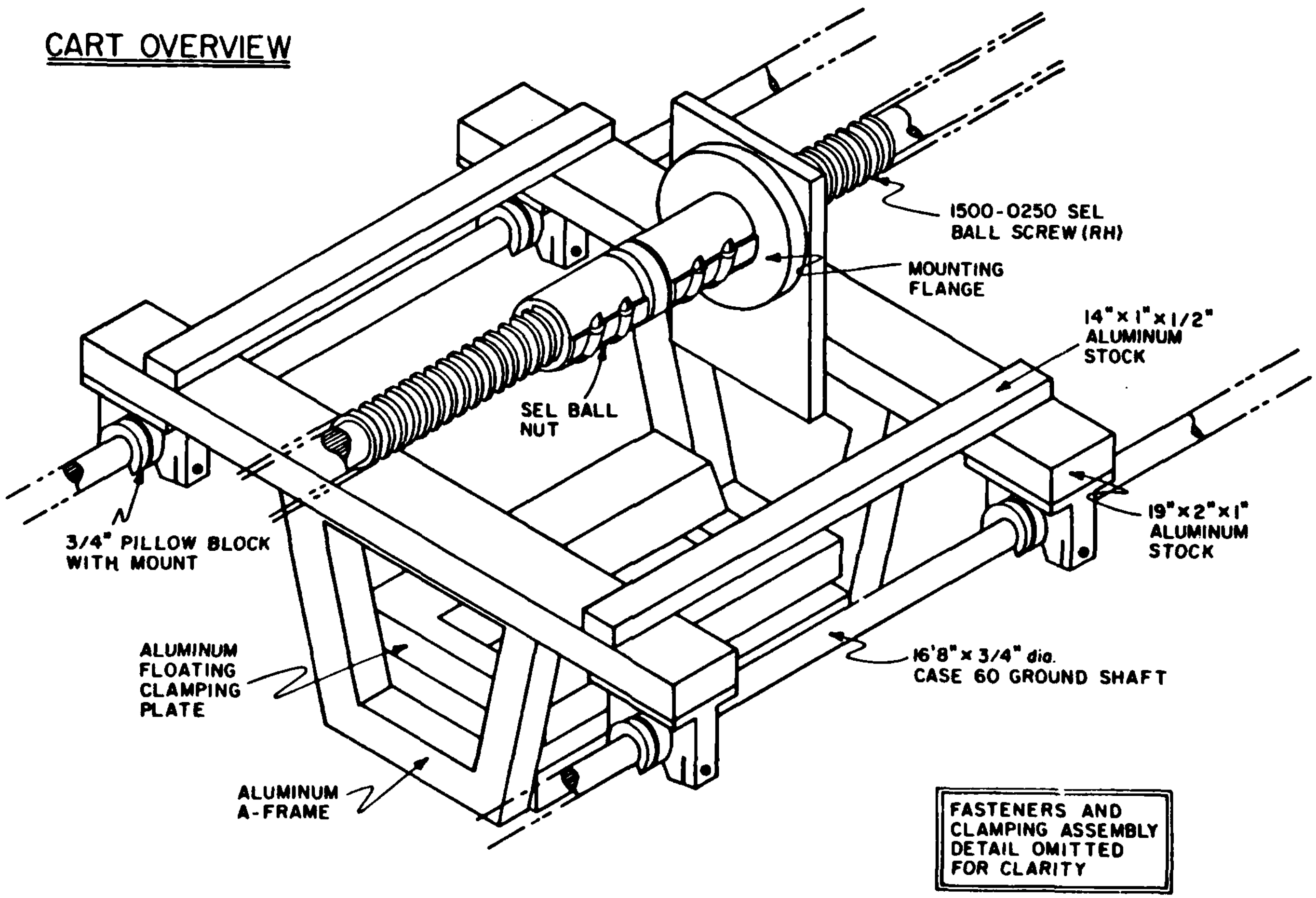

CART OVERVIEW
1500-0250 SEL BALL SCREW (RH)
MOUNTING FLANGE
14" x 1" x 1/2" ALUMINUM STOCK
SEL BALL NUT
19" x 2" x 1" ALUMINUM STOCK
3/4" PILLOW BLOCK WITH MOUNT
ALUMINUM FLOATING CLAMPING PLATE
16'8" x 3/4" dia. CASE 60 GROUND SHAFT
ALUMINUM A-FRAME
FASTENERS AND CLAMPING ASSEMBLY DETAIL OMITTED FOR CLARITY

Figure 11

constraining the transducer inside the cart. The holding plate has a tapered neoprene lined slot into which the transducer is pressure-clamped by the clamping plate. The pitch of the transducer can be controlled by varying the pressure applied by the wing nuts that hold the clamping plate in place on top of the cart. The holding plate is designed as a floating assembly within the cart. This design provides adequate control over both the pitch and yaw of the transducer, and also provides a good shock absorption system in the occurrence of a substantial momentum transfer to the transducer. This floating system is achieved by suspending the holding plate between two sets of compression springs. When the wing nuts are properly tightened, the nose of the transducer array will protrude from the bottom of the cart. The exact position of the transducer can be altered by increasing the amount of compression force that is applied to the top springs. This will also increase the damping force that is applied to the holding plate.

In order to obtain proper impedance matching as the ultrasonic signal passes from the transducer into the billet and back, the nose of the transducer is surrounded by a water bath. The water bath is contained within a clear Plexiglas shell. The Plexiglas shell is attached to the bottom of the nose plate with a metal flange. When the cart is lowered to the surface of the billet a rubber gasket clamped to the bottom of the water column provides a tight seal with the cannon billet.

The interface between the cart assembly and the linear tracking assembly is accomplished by the use of four open type pillow blocks. The pillow blocks are linear bearings that ride upon the shafts of the linear tracking assembly. Pillow blocks were chosen over conventional linear bearing assemblies because they will allow for a three degree deviation from the normal axial alignment without restricting linear movement. Open type pillow blocks are used so that support rails can be used for a more even load distribution in supporting the steel shafts along which the cart translates.

4.2 LINEAR TRACK ASSEMBLY

The linear track assembly is essentially the main support for the entire mechanical system. A drawing of the mechanical assembly appears in figure 12. The main elements of this structure are two 4 x 6 inch aluminum wide-flange beams. The beam structure is 25 feet in length and is not permanently attached to the testing table upon which the mechanical structure stands. The lack of rigid attachment is due to the necessity for

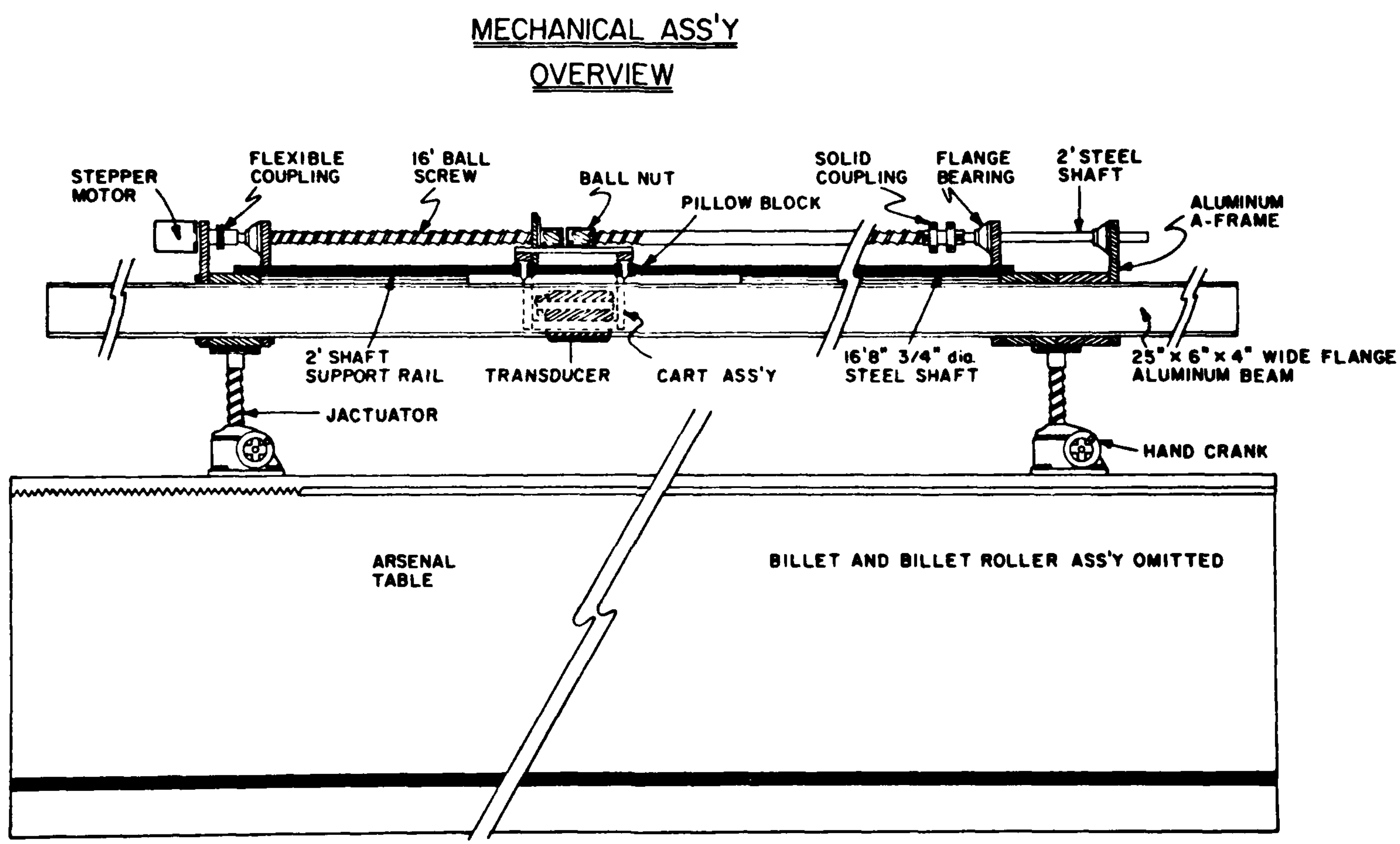

MECHANICAL ASS'Y
OVERVIEW
STEPPER MOTOR
FLEXIBLE COUPLING
16' BALL SCREW
BALL NUT
PILLOW BLOCK
SOLID COUPLING
FLANGE BEARING
2' STEEL SHAFT
ALUMINUM A-FRAME
2' SHAFT SUPPORT RAIL
TRANSDUCER
CART ASS'Y
16'8" 3/4" dia. STEEL SHAFT
25" x 6" x 4" WIDE FLANGE ALUMINUM BEAM
JACTUATOR
HAND CRANK
ARSENAL TABLE
BILLET AND BILLET ROLLER ASS'Y OMITTED

Figure 12

the beam structure to be removed while a billet is being loaded onto the table. This prevents the transducer from accidentally coming into contact with the billet while the billet is being loaded onto the testing table. This lack of rigid support necessitates that all bending moments that the structure is subjected to have to be eliminated or compensated for in the beam structure itself. With the cart in the middle of the beams the maximum deflection of the beam (this includes the deflection due to both the total load upon the beams and the bending moments that the beams are subject to because of the loading) will be a distance of .98mm. This stringent a tolerance is set in order not to cause any sacrifices in the data acquisition due to the transducer's orientation as it translates down the billet.

Attached to the wide-flange beams are the structures that support the drive system for the cart. These include four A-frames and the additional bearings and mounting hardware associated with them. One of these A-frames supports the stepper motor while the other three house flange mounted bearings. These bearings provide added support to the ball screw which will only be supported at the ends and by the reactive force from its contact with the ball nut on the cart. These A-frame and bearing systems are bolted to the wide-flange beams.

The remaining components of the mechanical assembly are the devices that hold the beam assembly above the test table on which the billet will be placed. Throughout the ultrasonic scanner's test life it will be used to test for flaws in billets ranging in size from 8 inches to 24 inches. To accomplish this four machine screw jactuators are used. These jactuators are raised and lowered by turning a hand crank. These units are connected in pairs at either end of the test table. A photograph of two of the four units appears in figure 13. The jactuators allow easy control over the vertical positioning of the entire assembly with respect to the billet. The jactuators will be bolted directly to the test table provided by the Benet Weapons Lab. The use of these jactuators makes the job of correctly leveling the entire assembly significantly easier than if threaded rod and nut assemblies were to be used.

4.3 STEPPER MOTOR SUBSYSTEM

Of the many subsystems that make up the ultrasonic imager, there are two which serve to interface the two environments in which the system must function. The first of these systems, and of prime importance, is the ultrasonic array which has been dealt with earlier in

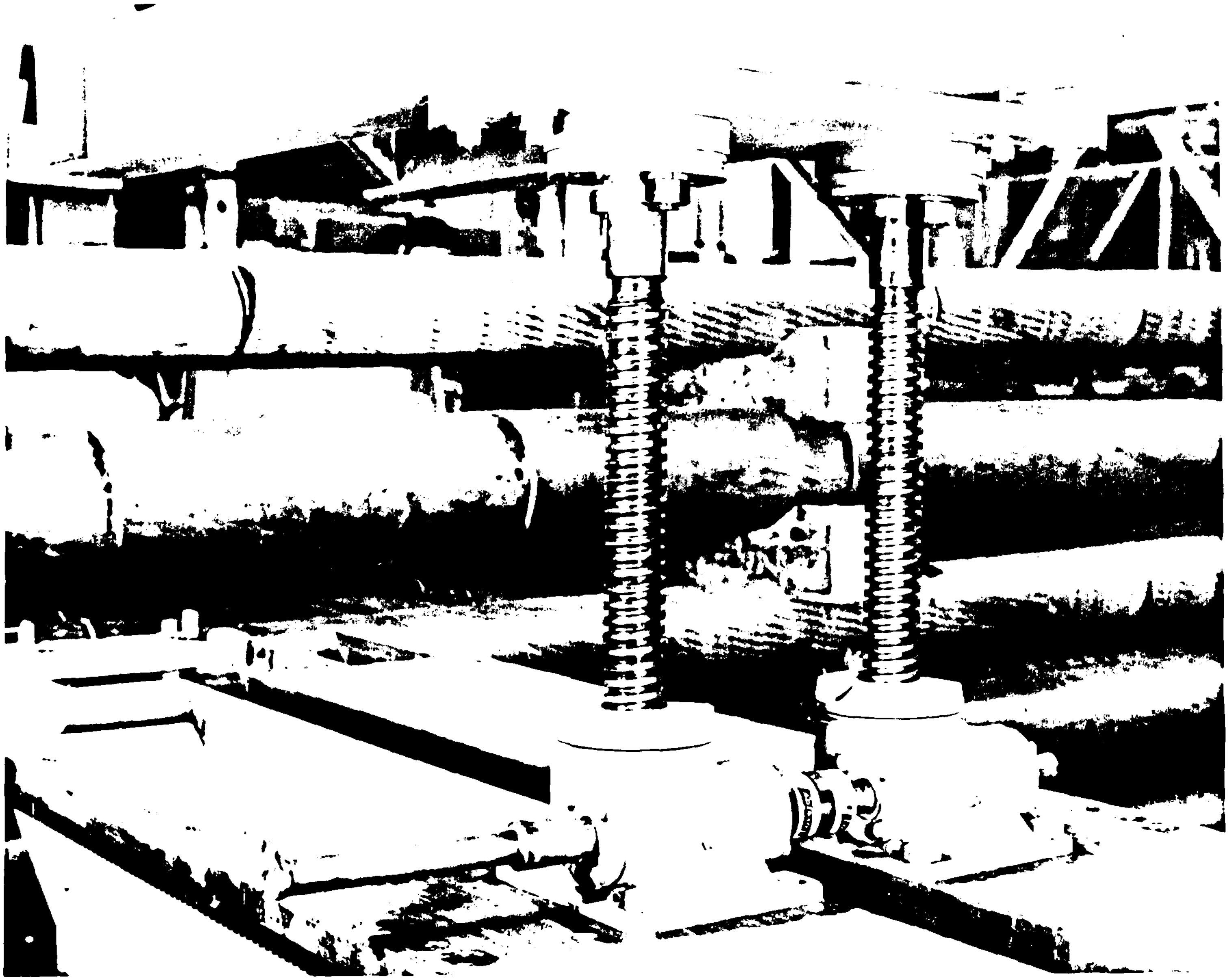


Figure 13. Pair of Jactuators.

this technical report. The stepper motor and its associated controls are the second main interface between the electrical and mechanical systems of the ultrasonic imager. The stepper motor provides an accurate method of positioning the cart/array over the billet.

Electrically the stepper motor system features two switches that indicate right- and left-hand travel limits and a third input which indicates the direction of movement of the cart/array over the billet. Mechanically the stepper motor is mated to an A-frame which is part of the cart/array support system. A photograph of this A-frame appears in figure 14. The stepper motor shaft is joined to a ball screw via a flexible disc coupling; this serves three purposes. Initially, the flexible coupling is used to smooth the torque conversion between the stepper motor and the ball screw. In this fashion the cart moves smoothly and maintains itself correctly aligned with the billet. The coupling also serves to correct potential misalignment with quick starting and stopping of the cart.

A ball bearing screw is used as the drive for the cart because it replaces the sliding friction associated with conventional power screws with the lower rolling friction of ball bearings. A photograph

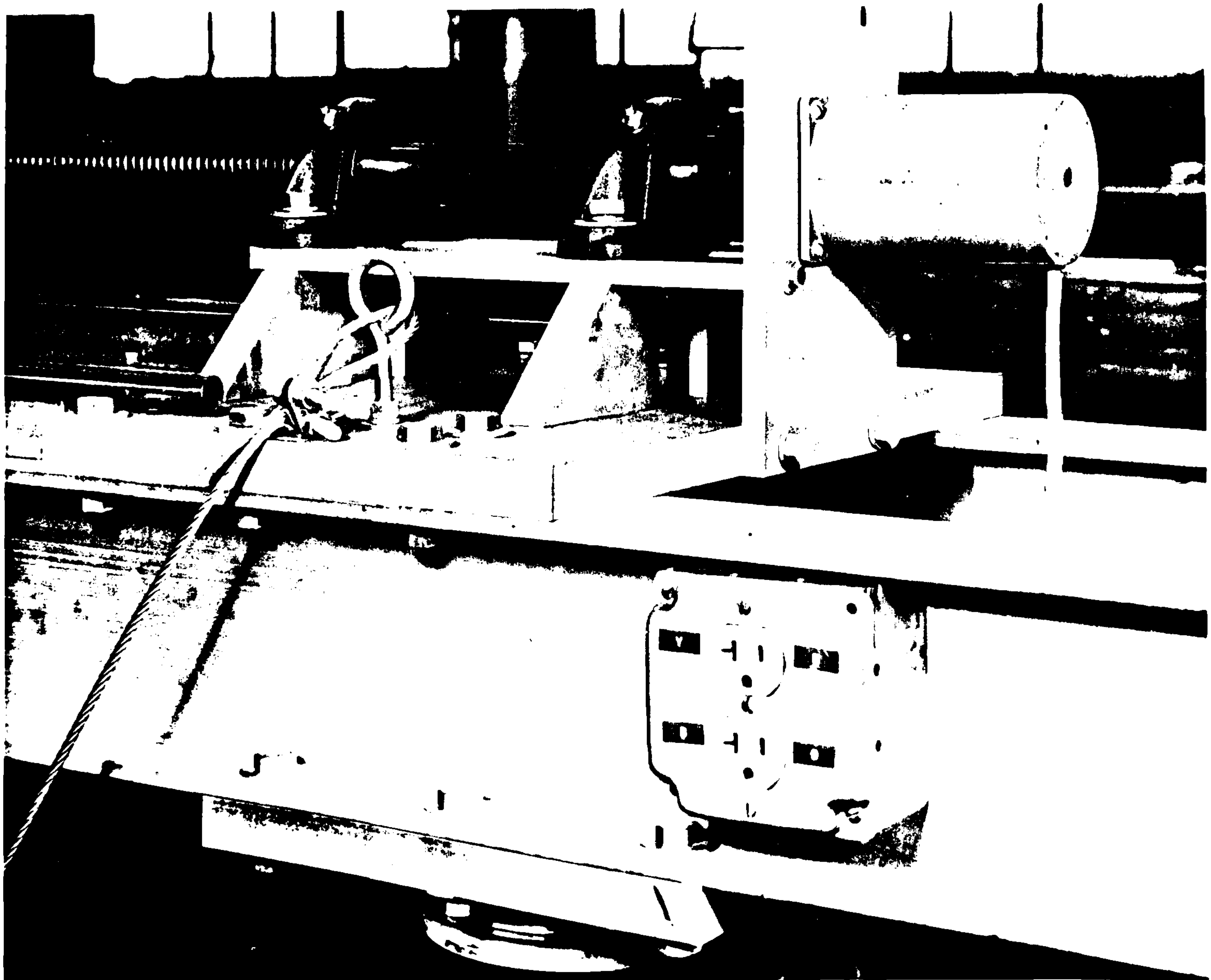


Figure 14. Support of Stepper Motor.

of the ball bearing screw and the transducer cart assembly can be seen in figure 15. The ball screw transfers the rotational motion associated with the stepper motor into translational motion of the cart. The lower amount of friction due to the ball bearing provides a more efficient method of powering the cart. This system will move the cart so that the billet can be easily scanned along its total length.

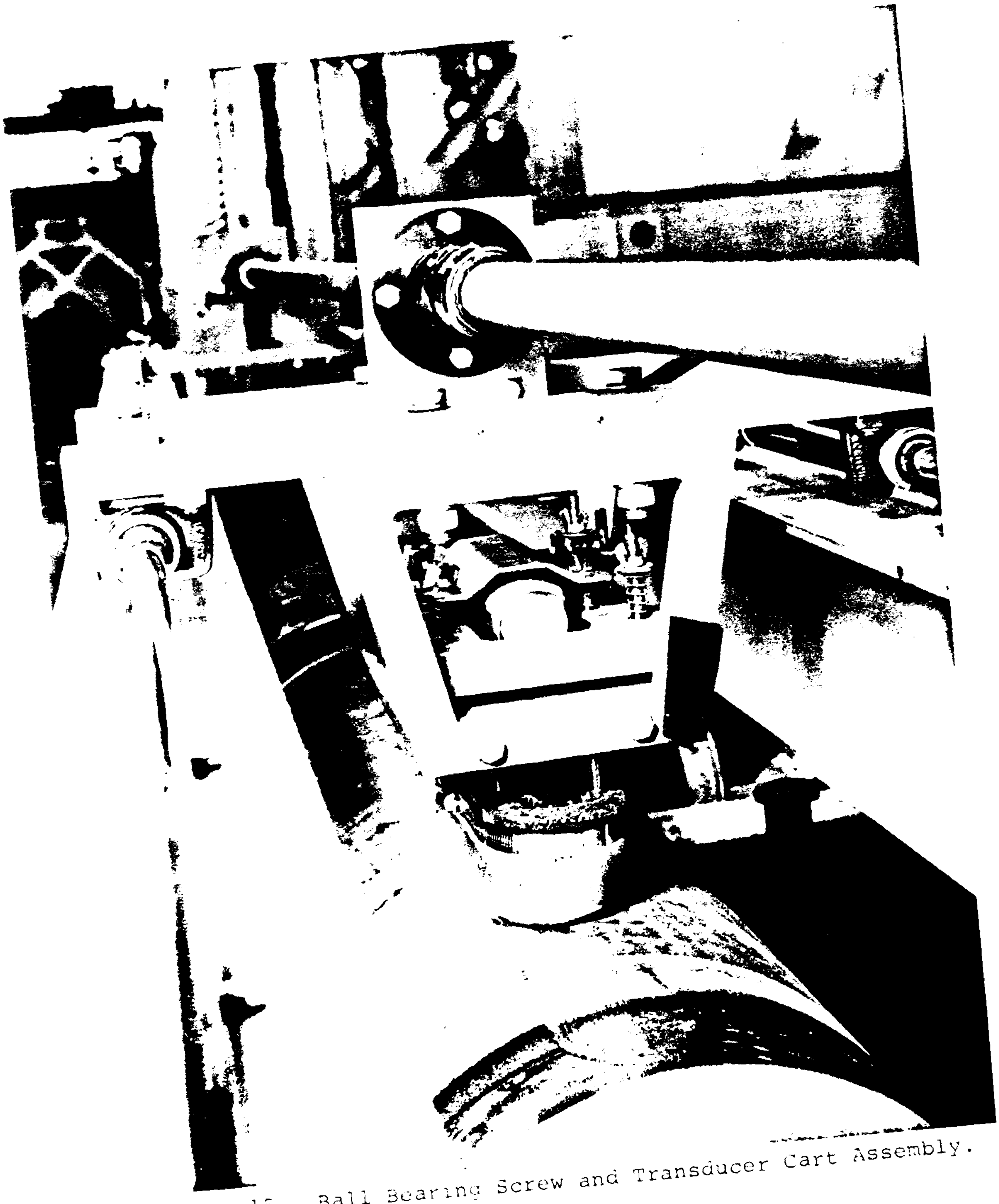


Figure 15. Ball Bearing Screw and Transducer Cart Assembly.

PART 5

SYSTEM OPERATION

5.1 MECHANICAL SET-UP AND ADJUSTMENTS

The mechanical set-up for the Ultrasonic Imaging and Automated Flaw Detection System can be described in three major steps, each of which has several adjustments and cautions which must be considered while the set-up is taking place.

A. Placement of Billet

It has been discovered that the cannon billets do not possess a perfectly round outer surface so it is safe to assume that the level of water in the bath surrounding the transducer will be changing as the billet rotates. To allow for this a catch basin must be placed below the entire section of the billet which is to be scanned. Adjust the rollers to safely support the cannon billet while leaving enough room below the billet for a basin to catch any water which might leak out of or overflow from the water bath for the transducer array. There is a crank on each roller assembly to allow for the operator to move the rollers to the desired position. Once the rollers are in the appropriate position, place the cannon billet on the rollers and mount the triangular stop at the south end of the billet. The south end of the billet will be considered the end which points towards the band saws at the Watervliet Arsenal, and the north end will be the end which points towards the forge.

B. Mounting of the Jactuators

Four machine screw jactuators have been chosen for the purpose of supporting the Linear Tracking Assembly (LTA) and keeping it in a fixed position. As mentioned earlier in this report, the four jactuators are connected in pairs by means of a flexible disc coupling. To assemble these main supports the coupling must first be slid back out of the way. Place the jactuators into the holes which have been cut out of the table, and line up the crank shafts on each pair of jactuators. Now slide together the flexible disc coupling and secure each half to its crank shaft. Each jactuator must be securely bolted to the table to ensure the LTA remains rigid.

C. Mounting the Linear Tracking Assembly

Proper positioning of the array relies only upon the assumption that the LTA be level. The same assumption was made about the top surface of the cannon billet as it sits on the rollers. Adjusting the assembly in the length direction is not a problem as each pair of jactuators can always be raised or lowered in tandem. But each jactuator must first be adjusted so it is level with its mate before the LTA can be attatched.

First, raise all four jactuators to a height that will not allow the transducer cart to come in contact with the billet when the LTA is lowered. Adjust each pair of jacks by placing a level across the top of both jacks and then raise or lower them individually as required. Each jack can be adjusted separately by holding the flexible disc coupling while rotating the top plate of the jactuator. Once each pair is level, the Linear Tracking Assembly can be lowered onto the the jactuators. Be careful to align the pins on the bottom of the LTA with the large holes on the top of the jactuators. The LTA should be oriented with the stepper motor at the north end of the table.

D. Accutrol 100

During installation of the system, it was discovered that the rollers which are mounted on the table supplied by Benet Weapons Laboratory turned the cannon billet faster than had been expected. In order to slow down the AC induction motor which powers these rollers, the Accutrol 100 motor control was purchased from Westinghouse Corporation. A photograph of this unit apppears in figure 16.

The Accutrol 100 Adjustable Frequency Control uses solid state technology to adjust both the frequency and the voltage applied to the terminals of 3-phase AC motors. Since the speed of an AC motor is proportional to the applied frequency, this allows the speed of the motor to be changed either above or below its rated nameplate speed.

While the Accutrol 100 is capable of substantial speed adjustment the operator must be aware that the AC motor which is being controlled is a self - cooling motor. Therefore, at lower speeds the shaft mounted fan provides reduced cooling. Care must be taken not to overheat the motor. It was determined that an initial speed setting of 3 provided a slow enough speed to accurately detect flaws. Higher speeds will provide less accurate flaw detection while lower speeds will cause the motor to heat up quicker.

E. Adjustment of Jactuators

The second adjustment of the jactuators can now be made. Lower the LTA until the rubber gasket at the bottom of the transducer cart comes in contact with the cannon billet. Place the submersible water pump in the

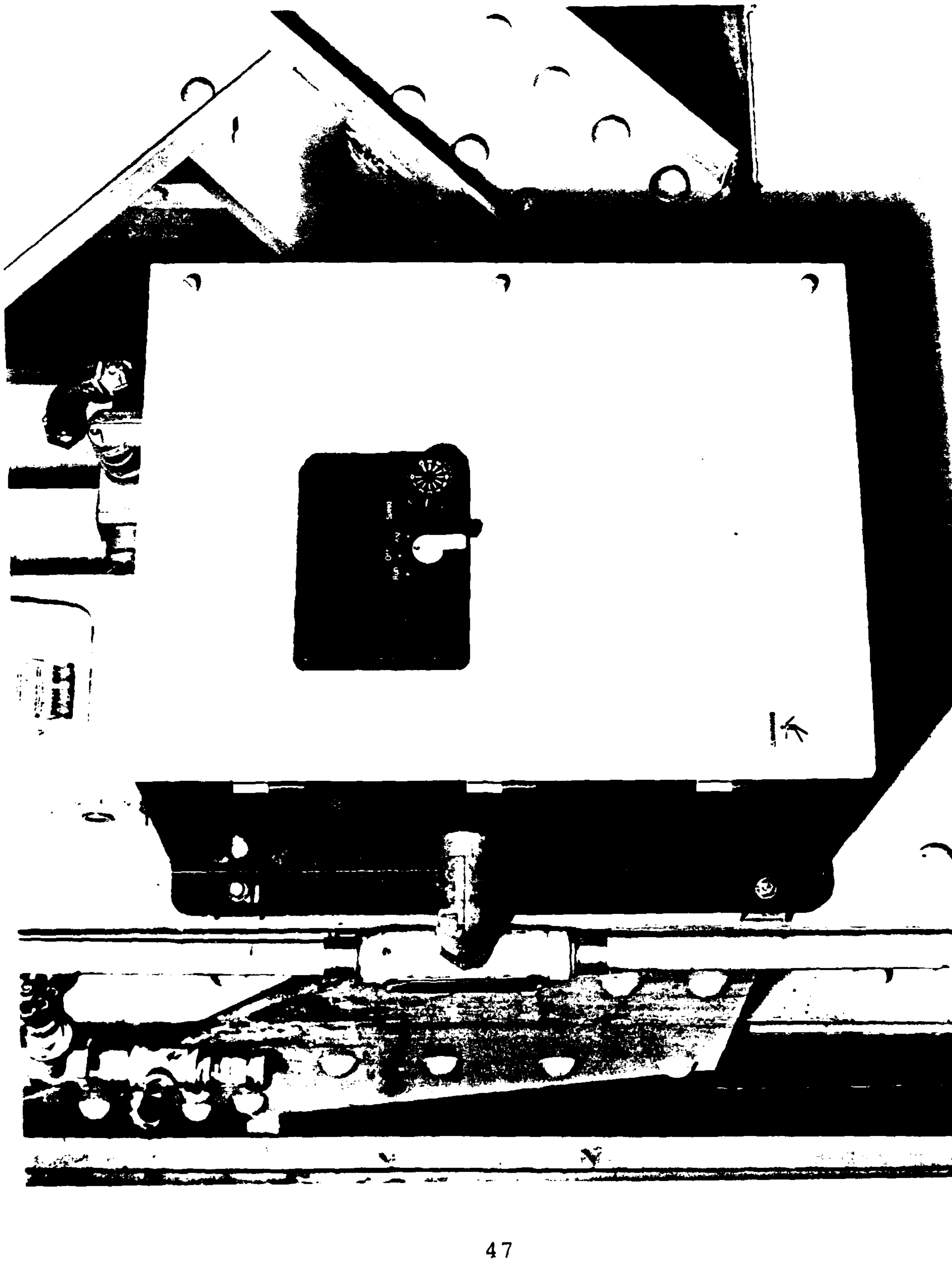


Figure 16. Accutrol 100.

basin of water below the billet and place the outlet hose into the hole provided at the south end of the cart assembly. Now adjust the jacks until the LTA is level in the length direction.

The final adjustment which must be made is the water level in the bath created by the transducer cart. This will only be a problem if the outer surface of the cannon billet is not perfectly round. If the billet is round then the water bath need only be filled once and no water will leak out. If it is not perfectly round then the height of the LTA, and the water pressure from the pump must be adjusted to maintain an adequate column of water.

The LTA should be lowered until it creates a good seal for most of the billet's revolution. But care must be taken not to lower the transducer cart to the point where friction from the billet will damage the clear Plexiglas shell at the bottom of the transducer cart. The flow of water should now be increased until the nose of the transducer is always surrounded by at least a half inch of water. If the water pressure is too great for the portion of the revolution when there is a good seal between the cart and the billet, the LTA may have to be lowered and the water pressure cut back. But once again, care must be taken not to lower the cart to the point where damage may result to the lower portion of the cart.

F. Electrical Interface

The final step involved in setting up the mechanical system is to connect it to the rest of the Flaw Detection System. Connect the large orange cables to the electrical outlet mounted on the north end of the Aluminum I-Beams. Note the proper orientation of the cables. If they are reversed damage to the stepper motor may result.

There are three switches which must be attached to the mechanical system. Two of the switches will sense when the transducer cart has reached either end of the path which it is allowed to travel, and the third senses when a revolution of the billet has been completed. The two limit switches should be placed at the ends of the path you wish to scan and the third switch should be attached at the north end of the billet as seen in figure 17. The two limit switches should be placed with the arm of the switch pointing away from the transducer cart and the third switch should be placed with its arm pointing in the direction the billet rotates. A small bolt must be attached to the end of the billet for proper movement of this switch.

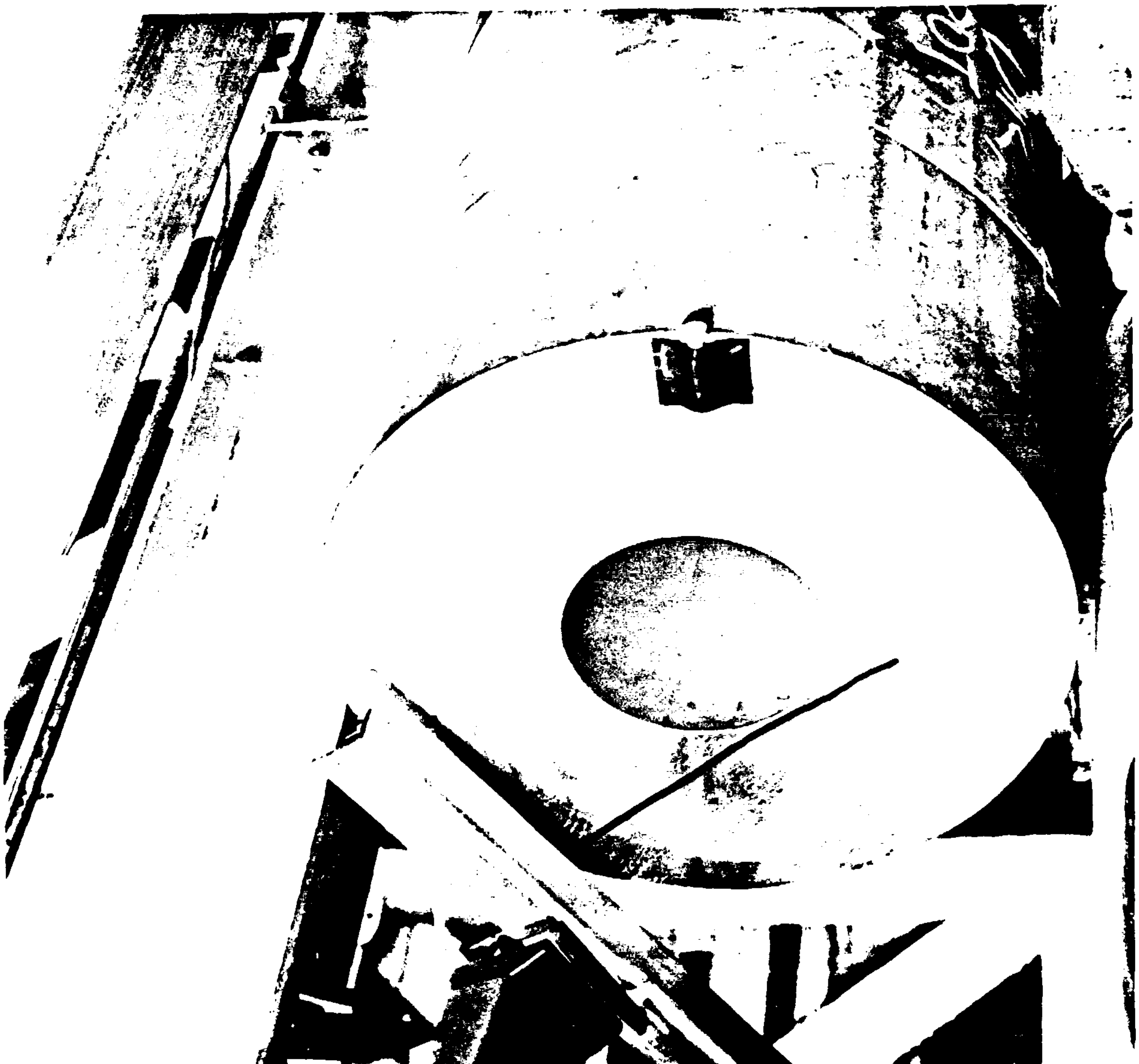


Figure 17. Placement of Rotational Switch.

Finally, the transducer array must be placed in the transducer cart. The transducer array is very fragile and must be handled with extreme care. Remove the clamping plate from the top of the transducer cart assembly. The transducer array should be placed into the cart from the top with the cable pointing towards the north and then looping around and coming out of the top of the cart assembly. Press the transducer into the neoprene lined slot until the nose protrudes through the bottom. Replace the clamping plate and tighten the wing nuts securely. The orientation of the array may now be adjusted as necessary.

5.2 COMPUTER OPERATION AND THRESHOLDS

To begin using the Flaw Detection System, the switch on the front of the Computer Cabinet must be placed in the START position. If this is not done, the software will not start up when the power is turned on. With the switch on the front of the stand in the START position, the power switch on the back of the stand may now be turned on. You will notice 3 small red indicators on the back of the stand light up. This merely shows that power has been applied to all portions of the system. As you walk around to the front of the stand and the CRT terminal warms up, you will see operator instructions and information printed on the screen.

```
INSTRUCTIONS FOR SYSTEM POWER UP
1 - TURN ON SWITCH ON FRONT OF STAND
2 - CONNECT TV AND STEPPER CABLES
3 - POWER UP TV AND STEPPER MOTOR
```

The switch on the front of the stand should now be placed in the ON position (down). The stepper cables are the large orange cables which connect the stepper motor driver to the stepper motor. If the entire mechanical system was just set up these cables were already connected as were the limit switches and probe. In any event, make sure these cables are connected before the stepper motor driver and the Searle unit are turned on. To continue with the instructions press any key on the CRT terminal.

The computer will then begin to initialize itself. For instance, the transducer cart will automatically move to the home position at the right limit switch. The computer will then ask the operator a series of questions. The first question printed on the screen will be:

ENTER DISPLACEMENT IN INCHES (0 TO 216)

This displacement provides the operator with the option of beginning the scan from a particular distance away from the home position. For instance, if earlier one day you saw some flaws one foot from the right limit switch and you want to look at them again you can enter a displacement of 12 inches and the transducer cart will automatically go to that position. From then on this position will be considered the home position. If you desire to leave the home position at the default position of the north switch then a <CR> or 0 may be entered. The next message that will be printed on the screen will be:

```
ENTER BILLET LENGTH IN FEET (1 TO 18)
NOTE: LENGTH + DISPLACEMENT CAN NOT BE OVER 18 FT.
```

Now enter the length of the billet you wish to scan. Movement of the array is limited to 18 feet so the sum of the displacement and the length of the billet can not exceed this distance.

Now that you have provided the computer with information about the billet which is to be scanned, it will begin to time five rotations of the billet. It will average these five numbers and use this time as a reference to calculate the current angle of the billet. When five full revolutions of the billet are complete, the computer will go into command mode. The operator now has complete control over the imaging system to exercise whatever portion he desires. The options available to the operator are:

FIRST MENU COMMANDS:
(S) - SET PARAMETERS
(P) - ALIGN PROBE
(C) - CLEAR FRAMESTORE
(D) - CHANGE DISPLAYED FRAMESTORE
(F) - FIND FLAWS
(Q) - SYSTEM SHUT OFF
(M) - EXTRA ROUTINES
ENTER COMMAND:

Select one of these options by striking the associated letter.

(S) - SET PARAMETERS

Select this option to examine or alter one of the gains or thresholds used by the system. The command choices will be replaced by a list of parameters which is shown in figure 18. The number in parentheses which appears after each parameter is the current value.

A parameter is selected for change by entering the letter listed before the parameter. The parameter and its current value will appear at the top of the screen. If you do not wish to change this parameter, return without entering any numbers. To change a parameter, enter the new value, then return. The new value will appear in parentheses next to the parameter name.

Exit this program option by striking RETURN. The program will then revert to command mode and present the command choices again.

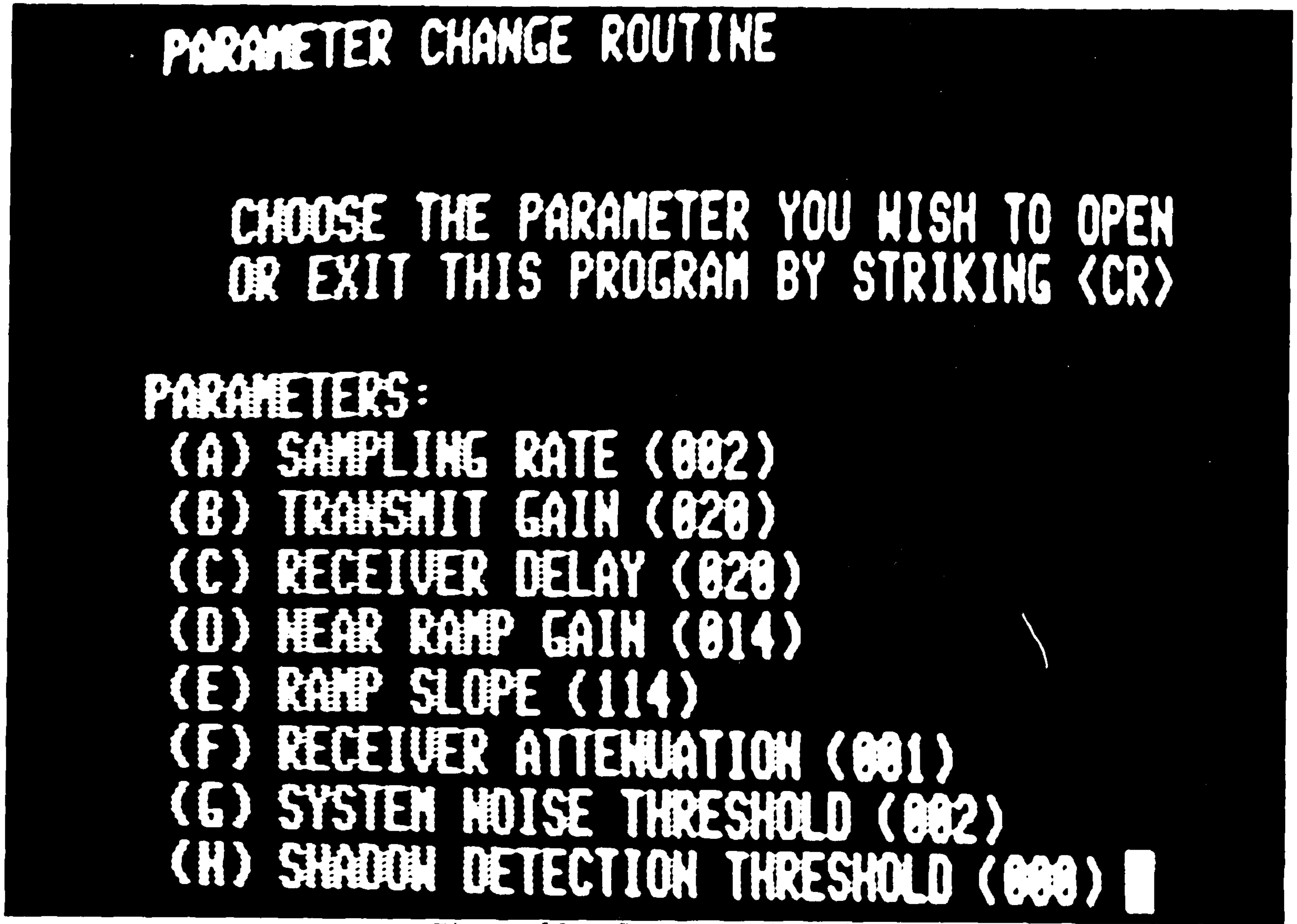


Figure 18. Set Parameters Menu.

The parameters and their functions are summarized below:

SAMPLING RATE - controls the rate at which the ultrasound is sampled. In terms of its affect on the image, it determines the size of the image field. The range of values is 1, 2, or 3. One will give the slowest sampling rate, hence the largest field; three will give the fastest sampling rate, hence the smallest field of vision.

TRANSMIT GAIN - corresponds to the transmit gain setting on the front of the Searle unit. The gain is measured in db down from the maximum, so the lowest number yields the strongest transmitted signal, and therefore the strongest reflected signal. The range of values is from 1 to 30.

RECEIVER DELAY - is the wait time between the transmission of the ultrasound pulse and the beginning of sampling. Increasing the delay will cause the image to move up on the TV screen. Adjust the value so that the billet is centered on the screeen, with both the front and back walls visible.

NEAR RAMP GAIN - The amount of amplification the receiver provides varies as a function of time. This function is in the form of a ramp which starts out at some low value in the near field (the top of the TV screen) and then ramps up to the maximum as time increases. The reason for this is because the intensity of the reflected signal tends to decrease from farther into the sample. To allow for this, and to provide for a better image, the amount of amplification is increased for signals coming from farther into the sample. The near ramp gain is the amount of gain which will be applied to signals near the surface of the sample.

RAMP SLOPE - is the rate at which the receiver gain will increase with time.

RECEIVER ATTENUATION - allows a tenfold reduction in the returned image intensity. This should be left as initialized by the program.

SYSTEM NOISE THRESHOLD - is used to compensate for the ordinary noise present in the image. This value should fall between 1 and 4 under normal conditions.

SHADOW DETECTION THRESHOLD - is used to allow flexibility in the setting of a threshold for flaw detection. Increasing the value will make detection easier and increase the chance of false alarms.

Decreasing the value will reduce the false alarm error rate, but at a cost of possible flaws missed. The proper setting of the flaw detection threshold with respect to the sampled image is most important to the actual implementation of the system in the manufacturing environment.

(P) - ALIGN PROBE

The probe must be adjusted until it is parallel with the billet. A graph will appear on the TV screen showing the backwall illumination function. In addition, a message will be displayed indicating the row numbers where the backwall image appears. The illumination function should be adjusted to be as flat as possible. The row numbers correspond to the location of the backwall as seen using the sampling program. There are 256 rows on the TV screen.

Return to the command mode by striking RETURN.

(C) - CLEAR FRAMESTORE

This option will clear the framestore which is currently displayed on the screen. The program returns to command mode automatically.

(D) - CHANGE DISPLAYED FRAMESTORE

This is used to look at one of the framestores, or to bring one onto the screen so that it can be cleared. This may be necessary if an unusual event causes an unwanted image to appear on the screen. A prompt appears when this option is entered. Return to the command mode by striking RETURN.

(F) - FIND FLAWS

This option is the most powerful of all, and comprises the bulk of the software. When this section of the software is entered the system will first align itself with the zero angle mark on the billet and then begin to scan the entire section of the billet specified on power up. It will continuously take samples and check them for flaws. When a flaw is found, its displacement from the home position and angle will be logged and the total number of flaws found will be displayed upon completion. The exit from this routine will place the operator in the second command mode. The second command level has the capability to go back and examine a portion of the billet where a shadow has been cast on the backwall. It then allows the operator to move the array by small amounts to get a better image of the flaw. The second command level also allows the operator to look at the list of all the flaws that were located and recorded.

(Q) - SYSTEM SHUT OFF

When you desire to shut off the system, these instructions should be followed:

(M) - EXTRA ROUTINES

Selecting this option will make another command level available with routines which the operator may find useful. Here are the names of the routines which will be printed on the screen:

```
EXTRA MENU COMMANDS:
 (C) - SINGLE SHOT FLAW DETECTION
 (D) - REPEATED FLAW DETECTION
 (U) - UPLOAD FRAME STORE
 (Q) - SYSTEM SHUT OFF
 (F) - EXIT TO FIRST MENU
 (S) - EXIT TO SECOND MENU
 (H) - MOVE MOTOR TO THE HOME POSITION
 ENTER COMMAND:
```

These commands are not imperative for the proper functioning of the system, but merely conveniences which the operator may find useful. None of these command choices are extremely complicated and the functions are fairly obvious from their names:

(C) - SINGLE SHOT FLAW DETECTION

This option will take a single image from the Searle Unit and analyze it for flaws. The sample will be taken at a random position, whatever position the billet happens to be in when the option is selected. If any flaws are found in this image the flaws will be marked on the TV screen but not placed in the flaw log.

(D) - REPEATED FLAW DETECTION

This option will provide the operator with a continuous scan of the billet. It will take a sample at random, analyze it, report the results, and then repeat the process over and over until the operator presses RETURN. There is no movement of the array under this option, so the scan will encompass only the portion of the billet which happens to pass under the array.

(U) - UPLOAD FRAMESTORE

The system also has the capability to send a copy of the image in digital form to another system. This could be useful for more detailed analysis, to store an image permanently, or perhaps to display an image on a more sophisticated video terminal.

(Q) - SYSTEM SHUT OFF

This is the same option described earlier under the first menu commands.

(F) - EXIT TO FIRST MENU

This command is self-explanatory; it will send you to the first command level which has already been explained.

(S) - EXIT TO SECOND MENU

This command will send the operator into the command level which allows him to view a specific flaw. If the find flaws routine has not yet been run, then no flaws will have been logged and exercising the second command level will not yield any information. The second command level is described in more detail later in this report.

(H) - MOVE MOTOR TO THE HOME POSITION

Selecting this option will move the transducer cart assembly to the home position selected on power up. The same command choices will then be presented to the operator again.

The second menu commands give the operator the capability to go back and look at the flaws that were located under the find flaws routine. The operator can then assure himself whether or not the image contains a flaw or not. The second menu also allows the operator to look at a list of all the locations where shadows were found on the backwall. The operator can then use this list to determine which specific flaws he wants to look at. Here are all the options which will be presented to the operator under the second menu:

```
SECOND MENU COMMANDS:
(S) - SHOW FLAW LOG
(L) - LOOK AT FLAWS
(C) - CLEAR FRAMESTORE
(D) - CHANGE DISPLAYED FRAMESTORE
(Q) - SYSTEM SHUT OFF
(M) - EXTRA ROUTINES
 ENTER COMMAND:
```

(S) - SHOW FLAW LOG

The flaw log is the list of locations where shadows were found on the backwall of an image. The format of the flaw log gives the operator a flaw number and the position of the flaw in terms of a distance from the home position and an angle away from the reference position.

(C) - CLEAR FRAMESTORE

(D) - CHANGE DISPLAYED FRAMESTORE

(Q) - SYSTEM SHUT OFF

(M) - EXTRA ROUTINES

These four options have been discussed earlier in this report.

(L) - LOOK AT FLAWS

Once the number of a particular flaw has been determined by looking in the flaw log it can then be displayed using this option. When this command is selected, the operator will be prompted for the number of the flaw:

ENTER FLAW NUMBER OR <RETURN> TO EXIT

When a valid flaw number is entered, the system will move the transducer to the correct position along the length of the billet and then align itself with the zero angle position of the billet. When the system finds that it is at the correct angle around the billet, it will take a sample and once again analyze it for flaws. When a shadow is found and a flaw located, the flaw will be highlighted with a box on the TV screen. While the operator is looking at the flaw he also has the capability to reposition the array by small amounts to get an even better picture of the flaw. Here are the options the operator will have when he is viewing a specific flaw:

LOCATE MOVEMENT INSTRUCTIONS:
(S) DO ANOTHER OR EXIT
(H) TO MOVE LEFT
(L) TO MOVE RIGHT
(K) TO MOVE UP
(J) TO MOVE DOWN
(P) DISPLAY PRESENT LOCATION

(S) DO ANOTHER OR EXIT

To exit this mode of operation or to look at another flaw in the flaw log this option should be selected.

(H) TO MOVE LEFT

This option will move the transducer cart assembly one-quarter inch to the left.

(L) TO MOVE RIGHT

This option will move the transducer cart assembly one-quarter inch to the right.

(K) TO MOVE UP

This option will increase the angle at which a sample is taken by a fraction of a degree. This fraction is determined after the rotation of the billet is timed on power up.

(J) TO MOVE DOWN

This option will decrease the angle at which a sample is taken by a fraction of a degree.

(P) DISPLAY PRESENT LOCATION

Select this option to display the location at which the system is currently taking samples. If the operator moves the position of the array from the location listed in the flaw log it will be reflected here. This will not however change the location which has been entered in the flaw log.

5.3 THE TYPICAL SCAN OF A BILLET

At this point we have discussed setting up the entire mechanical system and the operation of all the computer software in great detail. Because the system was described in such a detailed manner, we now give a simplified description of how the system can be used.

First, the mechanical system must be in place. If it is not or you wish to mount a new billet then the directions described in section 5.1 must be followed.

Once the mechanical system is set up you can proceed to the second part of the system's operation -- the LSI-11 microcomputer. With the switch on the front of the stand in the START position turn on the power switch at the rear of the stand. Instructions will appear on the CRT terminal as it warms up. Follow these instructions and make sure to never connect the large orange cables while the power switch on the Sigma stepper motor driver is turned on.

After you have completed the power up instructions, you will have to describe what portion of the billet you wish to scan. You will be asked for a displacement (where you want the scan to begin) and how much of the billet you wish to scan. The system will then initialize itself. It will clear both framestores and move the transducer cart to the home position.

Now the complete system will be available to the operator. The first adjustment which needs to be made is to align the probe. When the align probe routine is run, a graph will appear on the TV screen. This curve is a measure of how well each part of the backwall is illuminated. One such curve appears in figure 19. Adjust the probe until a reasonably flat curve is displayed on the TV screen. This curve will never be perfectly flat due to variations in the gain of individual crystal elements, but it is still a good measure of the adjustment of the probe. A second method to check the alignment of the probe is to run the repeated flaw detection routine in the menu of extra routines. You will want the top of the billet and the inner bore surface to be parallel to the face

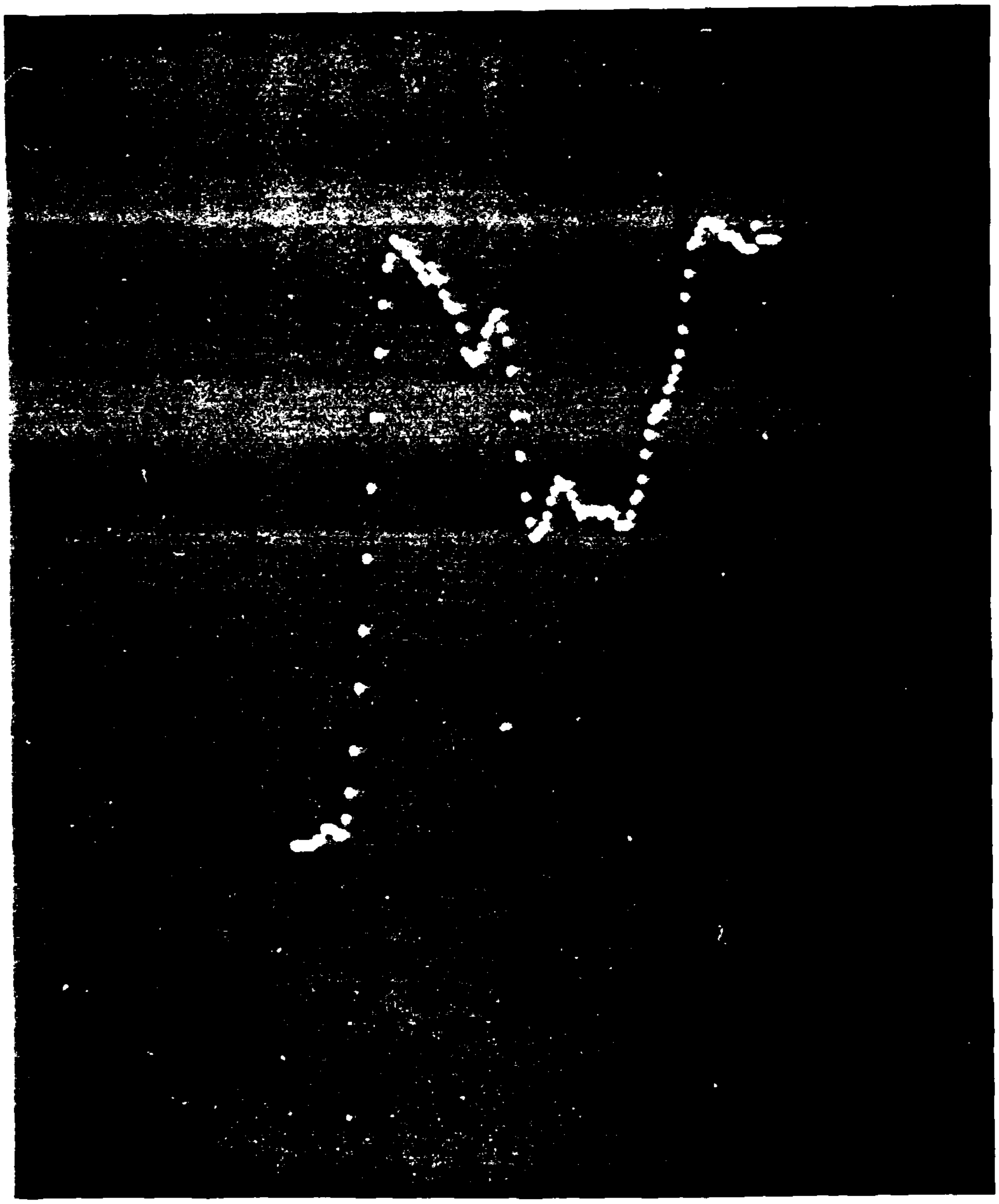


Figure 19. Backwall Illumination Function.

of the array. The picture on the TV screen is in reference to the probe so you can check this alignment by making sure these reflections are as horizontal as possible on the TV screen. Another feature you will want to check is how often the software detects flaws. If it constantly reports that shadows are present in the backwall, then further adjustment is necessary. Perhaps you will want to raise the transmit gain to get a stronger reflection with less shadows, or you could also increase the receiver ramp gain to provide you with more amplification in the receiver.

Once you have centered this image on the TV screen and you are satisfied that the system is accurately reporting when flaws are present you are ready to go back to the first menu and scan the billet. When the find flaws routine finishes it will report back how many possible flaws it has found and then send you into the second menu of control commands to examine the flaws.

Now you can choose which portions of the billet you wish to reexamine by looking into the flaw log. You can go to any of these locations by using the look at flaws routine. The operator can adjust the position of the array in order to convince himself whether or not a flaw is actually present.

This would conclude a typical scan of a billet. The power down instructions should be printed on the screen and followed to ensure that the next time the system is powered up the software will start automatically.

PART 6

PERFORMANCE TESTING AND RESULTS

6.1 FLAW IDENTIFICATION

The system was tested on a section of an actual billet. Several screw holes were drilled in the billet. One hole was drilled into the outer surface, two in from the edge at different depths, and two up from the inner surface.

Early testing gave unconvincing results. The identification process broke down in the upper half of the image due to interference from the interface. Modification of the program to test the background resulted in improved detection. One of the flaws which was at a depth of about four inches was now detected, but the top two inches were still opaque. This occurred because the ringdown from the interface was full-scale; it completely masked the flaw image.

It was determined that the ringdown was primarily because of the interface between the probe and the couplant. The probe was then suspended two inches above the billet. This separated the image from the ringdown. Adjustments of the transmit gain were made in an attempt to offset the attenuation of the two-inch gap. This attenuation was found to be severe because a water couplant was used. Later it was determined that glycerine, which has an acoustic impedance much closer to that of the steel, made a superior couplant.

With the software refined and the probe separated from the billet by the two-inch gap of glycerin, the system identified 1/4" screw holes at all depths in the billet.

6.2 DETECTING THE SHADOW

The width and relative intensity of the shadows were found to vary with depth as well as size of flaw. This effect has been attributed to the beam spreading inherent in the imager which acts like a fixed focal depth lens. The focusing is at its best near the outer surface of the billet. The shadow cast by a flaw near the outer surface is narrow and sharply defined. The intensity of each pixel in this shadow is one-third or less of the average along the trailing wall. A flaw located near the back wall is less well defined. The shadow from this flaw is spread across the image from the inner wall. The intensity drop is less pronounced; still it was found to be sufficient for reliable detection with appropriate threshold settings.

Extensive experimentation with the thresholds and sampling window along the inner wall produced a program that identified flaws at all depths with a minimum of false hits.

The program was also used to test the resolution of the imager and the software. Despite the smearing effects of the beam spread near the inner wall, good separation between the backwall and a flaw can be achieved as shown in figure 20.

Another experiment was set up using an actual billet with progressively smaller holes drilled into it. Figures 21 and 22 show slightly different views of this section of the billet. The bright streaks in these pictures are due to the fact that when the ultrasound signal hits the top of the flaw the entire signal is not reflected back to the array. Some of the energy continues into the flaw and bounces around between its two boundaries before returning to the array. These reflections will of course arrive at the array later in time, hence lower on the screen. Figures 20 and 21 show a 3/16 inch hole to the left, a 1/8 inch hole to the right, and a 1/4 inch hole in the center. The smallest hole detected had a thread diameter of 3/16 inch.

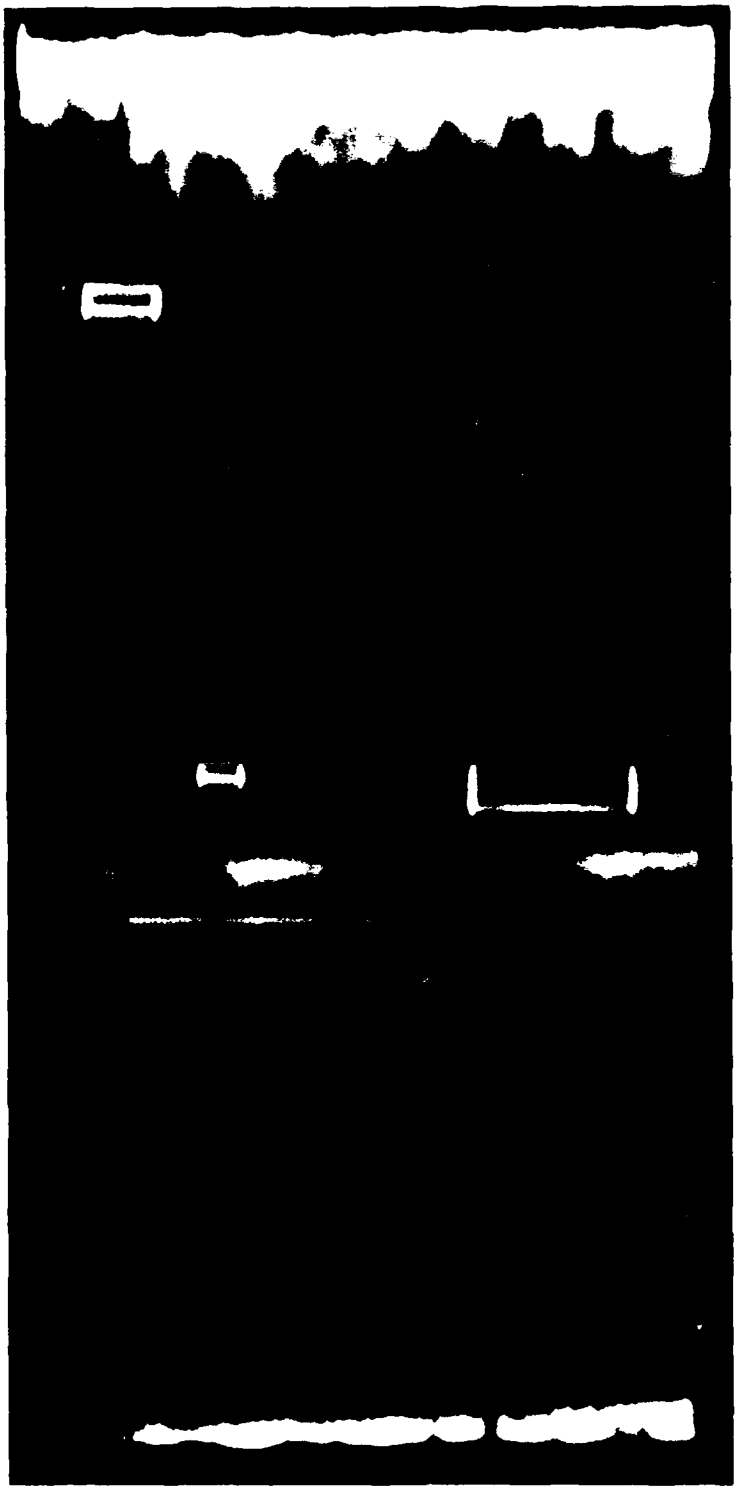


Figure 20. Photo: Resolution of Imaging System.

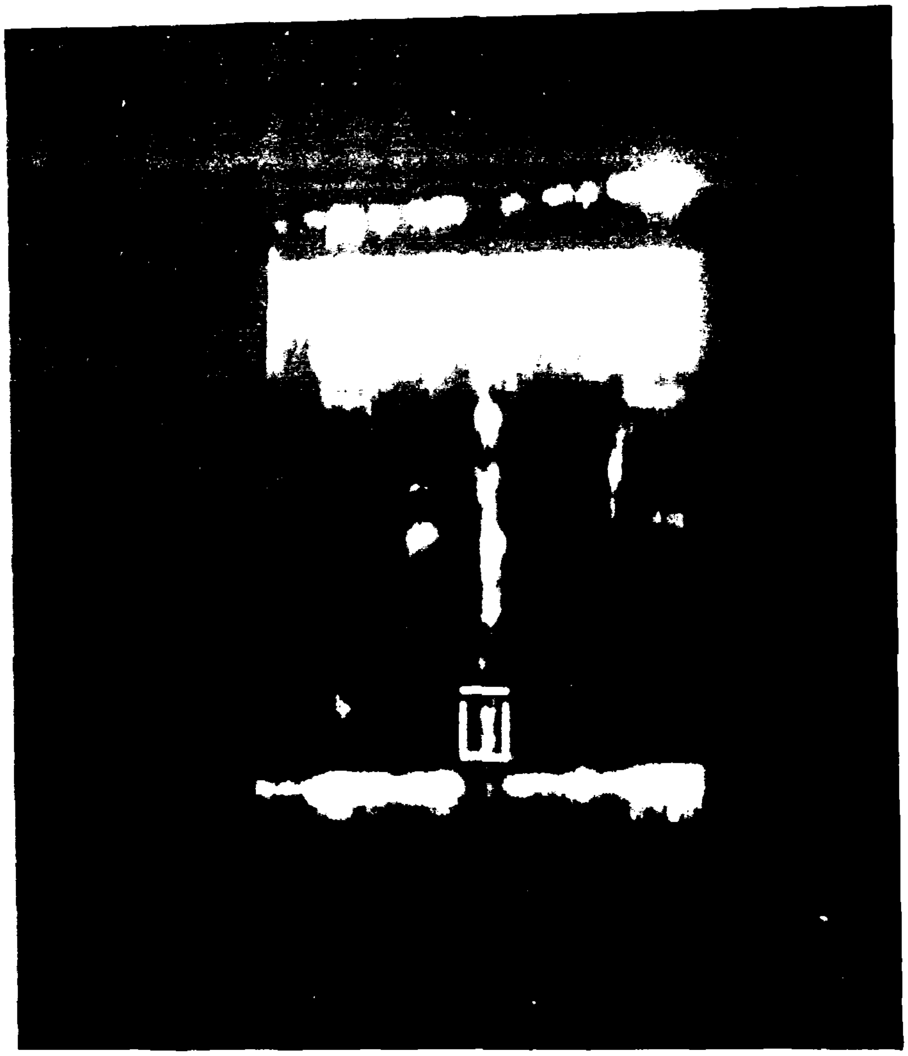


Figure 21. Photo: Identification of Increasingly Smaller Flaws.

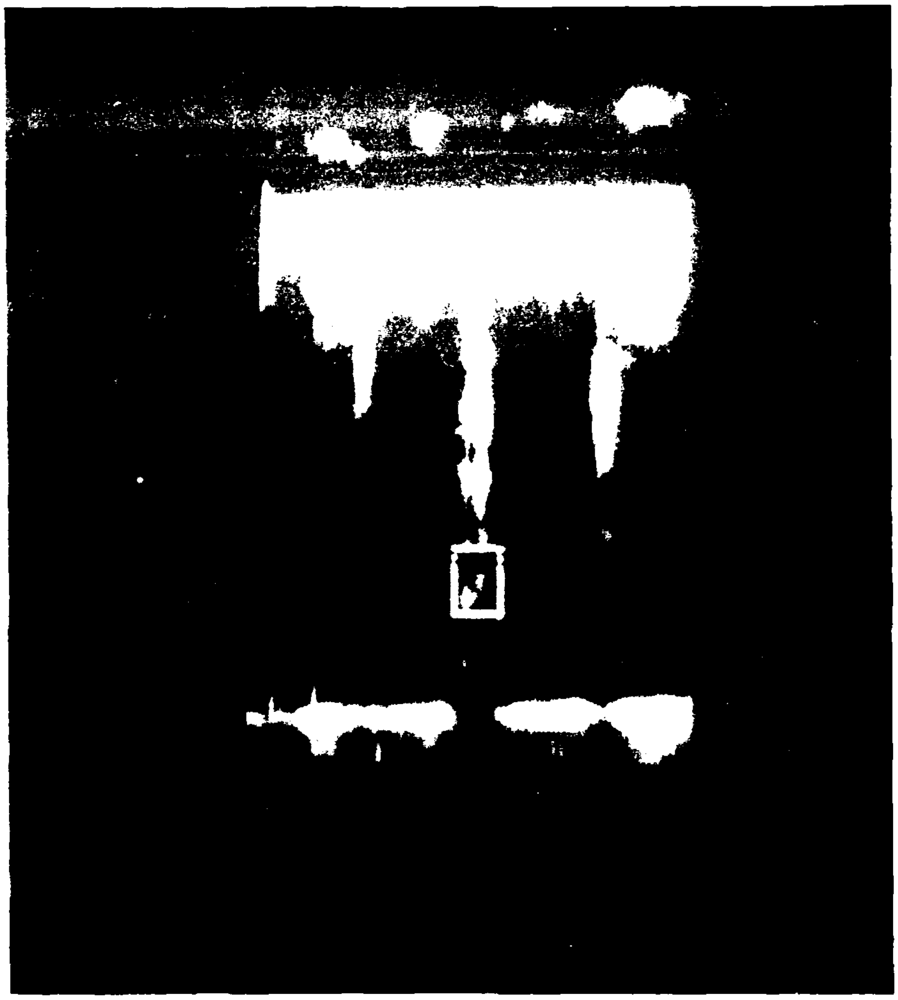


Figure 22. Photo: Identification of Increasingly Smaller Flaws.

Theoretically, the pdf of the samples along the inner wall is Gaussian-distributed in the absence of a flaw. In practice, the unbiased intensity function along the inner bore surface will not follow a Gaussian distribution. There will be some systematic error due to variations in the crystal array elements and their associated circuitry. This effect can be seen in the Backwall Intensity Function of figure 18.

When a flaw is present, a second independent distribution is produced. The superposition of these two distributions can result in a region of uncertainty where they overlap. This region is largest for flaws located near the center bore.

This uncertainty can be minimized in several ways. Optimal setting of the threshold between the image and its flaw will minimize error, but any practical threshold selector will only approximate this boundary. The focusing can also be optimized, but there are fundamental limits on the spreading of the beam. A convolver operating on the inner wall image can also cause great improvement in the sharpness of the boundaries. In software, the search can be made using groups of pixels at once. Although this acts as a low pass filter which tends to blur the image of the shadow, it improves the chances of finding a group of low-value pixels located directly under the flaw.

PART 7

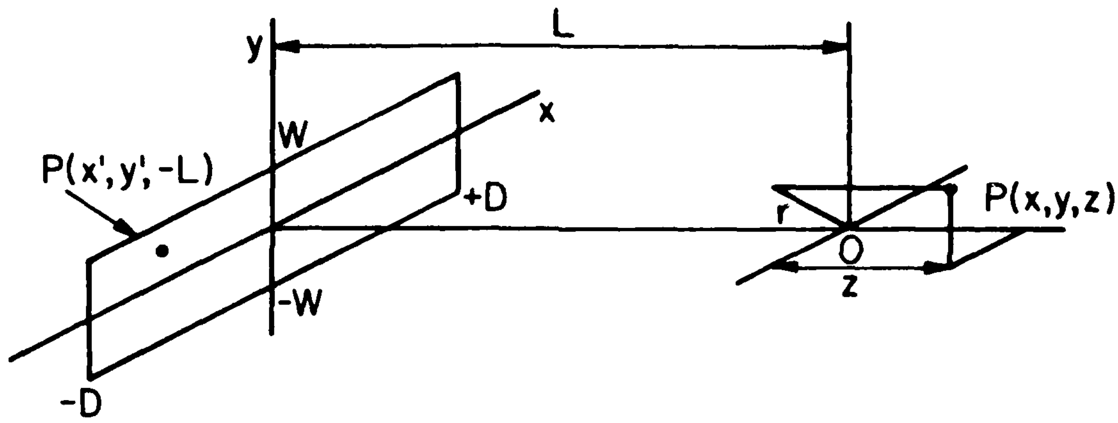
MATHEMATICAL STUDY OF RESOLUTION

7.1 APERTURE LIMITATIONS

Compensation for the beam spread function by deconvolution as discussed in part 8 is a useful augmentation for the phase one flaw detection system. Nevertheless, problems associated with system noise, analog part nonlinearities and dynamic range limit the usefulness of the deconvolution approach for aperture compensation. Therefore, phase two hardware is designed to address the limitations imposed by the size of the phased array, primarily by increasing the length of the array and the number of array elements.

Consider the geometry of the linear phased array shown in figure 23. Assume that the excitation in the rectangular aperture is focused only in the x direction towards the origin O. The field at a point x, y, z near the focus O can be written as follows using the Fresnel approximation [3,4]:

$$E(x,y,z) = \frac{iA}{\lambda L(L+z)} e^{-ikz} \int_{-W}^{W} \int_{-D}^{D} \exp\left[\frac{ik}{2L}\left(x'^2 + y'^2\right)\right] \cdot \exp\left[\frac{-ik}{2(L+z)}\left\{\left(x-x'\right)^2 + \left(y-y'\right)^2\right\}\right] dx'\, dy'$$



LINEAR PHASED ARRAY GEOMETRY

Figure 23

where A is the source strength and $k = \{2\pi/\lambda\}$ is the wave number. Restricting attention to the plane $y = 0$, we can explore the behavior near the focal spot due to the x-axis focusing.

Furthermore, let us first restrict x to 0 to study the behavior of the focusing as a function of z, the perpendicular distance from the focal plane to the observation point. Then we find that

$$E(0,0,z) = \frac{iA}{\lambda L(L+z)} \sqrt{\frac{2L(L+z)}{kz}}\; e^{-ikz} \left[\bar{\Phi}\left(\sqrt{\frac{kz}{2L(L+z)}}\; D \right) - \bar{\Phi}\left(\sqrt{\frac{kz}{2L(L+z)}}\; (-D) \right) \right]$$

where $\{ \bar{\Phi}(.) \}$ is one of the basic Fresnel integrals.

Similarly, by taking $z = 0$ we can explore the behavior of the focusing as a function of the lateral direction, x. Using similar mathematical manipulations we find:

$$E(x,0,0) = \exp\left\{ \frac{ikx^2}{2L} \right\} W \;\mathrm{sinc}\left(\frac{kxW}{L} \right)$$

where sinc(x) = sin(x)/x. The lateral width, s, of the focal spot is roughly

$$S = \frac{\ell\pi}{Wk} = \frac{\lambda}{2}\,\frac{L}{D}$$

as can be seen from the argument of the sinc function. The length of the focal spot is given by

$$\ell = \frac{\lambda}{\pi}\, a_\circ^2 \left(\frac{L}{D}\right)^2$$

Clearly, the larger the numerical aperture, D/L, the smaller the spot size will be in both length and width. Small spot width will be good for quasioptical signal processing such as is employed in the pulse-echo phased array of the phase one system, provided the spot length is not too small compared with the volume to be scanned since that system does not possess a dynamic focal depth capability. Depth information in the phase one system is determined by time of flight since the system is pulsed.

In the unfocused or y direction, the spot confinement is also of interest. In general, the y diffraction integral does not simplify mathematically to sufficiently give accurate beam width in the near (Fresnel) field. It can best be understood by examining the Cornu spiral. In basic terms, however, with no focusing along the y axis the extent, e, of the spot in that direction will be at least as large as the width of the aperture's geometric shadow plus an amount due to diffraction fringing. Hence, we have approximately a width equal to the aperture size, 2W, plus an estimated width taken from Fraunhofer considerations:

$$e = 2W + 2\lambda \frac{L}{W}$$

in the focal plane.

Now consider the following operating parameters:

λ = 0.6 mm

W = 1.0 cm

D = 1.0 cm

$$L = 20.0 \text{ cm}$$

These values are chosen to represent 4.0 MHz operation in steel, using only 16 elements at a time (as is the case in the phase one system). We find that the phase one beam has the following parameters:

$$s = 6.0 \text{ mm}, \quad l = 19.2 \text{ cm}, \quad e = 4.4 \text{ cm}.$$

This shows that the focal spot will be very large regardless of how the beam is formed simply due to aperture considerations. Nevertheless, the large focal spot is not a serious problem in a system designed primarily to detect flaws, but not to image or distinguish flaws. The high impedance mismatch present at the flaw interface assures that energy will be returned into the aperture with sufficient signal to noise ratio. The advantages of high maintainability, rapid scanning capability, and low cost for the phase one system are therefore not compromised.

However, the poor lateral resolution of such a small aperture can only be handled by greatly increasing the array length. During phase two the entire set of 256 electrodes in the array aperture will be sampled simultaneously. Hence, in the phase two system the array aperture, D, will increase to 14 cm. Then the corresponding beam parameters will become

$$s = 0.43 \text{ mm}, \quad l = 0.98 \text{ mm}, \quad e = 4.4 \text{ cm}.$$

at the same depth previously considered. This greatly increased lateral resolution can be exploited to form high quality images using either simulated lens pulse-echo phased array processing or digital holography in two or three dimensions. However, the short depth of focus or focal spot length will demand a dynamic focal depth adjustment capability in the phased array signal processing, since a pulse will remain confined only while passing through the focal spot. For holographic processing, or quasioptic lens simulation, however, the phase two beam parameters will be practically ideal for this application.

7.2 PHASE TWO - DIGITAL HOLOGRAPHY

During phase two not only will the aperture length be dramatically increased, but the nature of the signal processing will be made fundamentally more flexible. The aperture will be discretely sampled at 256 uniformly spaced positions and the signals obtained at these array elements will be digitized. This will permit a wide variety of signal processing and imaging techniques to be employed. In theory, any manipulation of the data consistent with the signal to noise ratio, linearity, dynamic range and quantization accuracy of the acquired signals can be employed once the data is digitized. This includes simulated phased array lens processing with dynamic focusing, weakly focused pulse-echo array processing, and digital holography in two or three dimensions.

The three-dimensional form of digital holography [5, 6, 7] can be implemented if the three-dimensional amplitude and phase field f(x,y,z) of a wave satisfying the CW Helmholtz equation is spatially sampled in a planar aperture (say z = 0). Given that the field is entirely due to a backscattered wave, the two-dimensional Fourier transform

$$F(u,v,z) = \int\int U(x,y,z)\ e^{i\phi(x,y,z)}\ e^{-2\pi i(ux + uy)}\ dxdy$$

for the field at a given depth, z, can be obtained for any value of z from the value of F(u,v,0):

$$f(x,y,z) = F(u,v,z)\ e^{2\pi i(ux + uy)}\ dudv$$

This is a direct result of the fact that f(x,y,z) satisfies the Helmholtz equation [6]. By substituting any value of z into this equation and inverting the transform of F(u,v,z), one can obtain f(x,y,z) for that same value of z. Two-dimensional versions of this processing exist for samples obtained in a linear aperture. The result would be a trace of the field along a line at a given depth, z, from the array.

In order to implement this technique, the spatial sampling of the aperture must be made with array elements of very small dimensions in order that all of the backscattered plane (or line wave) components scattered by the flaw can be "seen" by each array element throughout the array aperture. Faithful reproduction of images can be expected only in regions where this "point" receiver approximation is met in practice, but the demands imposed by this criterion are no more severe than required by phased array focused lens simulation or any other imaging method. Development of an array technology which meets this objective is one of the ongoing objectives of this research program.

PART 8

IMAGE ENHANCEMENT BY DECONVOLUTION

8.1 DECONVOLUTION

It has been observed that the Searle unit's phased array probe has an objectionable lack of resolution in both the depth and width dimensions. This is because the phased array utilizes only 16 of the possible 256 array transducer elements during any given pulse-echo data acquisition. Groups of 16 elements are selected in progression along the width of the probe. In this manner, 118 distinct groups of elements are selected to acquire an entire image comprised of 118 vertical samplings of the steel. This simplified imaging strategy limits the optical aperture of the array to approximately one centimeter (the width of 16 elements), which in turn limits the resolution. A certain degree of synthetic aperture enhancement is feasible using deconvolution.

A deconvolution board has been proposed for the purpose of image enhancement and improvement of flaw detection reliability in the phase one system. This board will be interfaced to the LSI-11 Q-bus, will have direct memory access (DMA) capability, and a high speed (10 MHz) arithmetic capability for simple array processing.

Deconvolution has been proposed as a tool for enhancing the image sharpness. The cause of the impaired image sharpness has been traced to a resolution problem in the phased array probe, due to an effect known as the beam spreading function. We have observed that the beam spreading function is predictable and is limited by the aperture size of the array, as previously described. Since the phased array probe and the steel exhibit the properties of a linear system, the effect of this decrease in resolution can be studied using linear discrete systems theory such as Fourier and convolutional analysis [2].

The general effect of the beam spreading function is a blurring of the image and consequently an increase in the apparent size of any flaw or back wall shadow. Images which should have sharp (high contrast) edges are instead smeared into images with gradual intensity gradients. This effect occurs in both dimensions of the image, however the horizontal dimension (parallel to the back wall) is the most critical since most intensity comparisons are done along the back wall. Both the small aperture size of the probe and the limited number of transducer elements involved in the data acquisition have been shown to be causes for this spreading which can smear 0.25 inch features over an inch.

Actual images are currently being analyzed with the VAX 11/780 computer at R.P.I. These images were obtained by uploading the contents of the framestore to the VAX. Samples of intensities from the back wall (corresponding to a row in the framestore memory) are considered as numerical sequences, or vectors, that can be transformed and convolved.

In general systems theory, time is considered to be the independent variable but, in this case, we are dealing with spatial distributions and spatial frequencies, and hence displacement along the back wall is the independent variable. Since the back wall samples are discrete in both amplitude and displacement, we will be dealing with the Discrete Fourier Transform (DFT) and discrete convolution.

To correct the beam spreading effect, a digtal filter must be designed which will counteract the filter characteristic of the spreading function. Hence, we must first find the spreading filter characteristic by applying an impulse to the system and observing the response. The DFT of this response will be the desired spreading filter H(k), by definition. Symbolically we note that if X(k) denotes the DFT of the input and Y(k) denotes the DFT of the output then Y(k)=H(k)X(k). Note that if the input is an impulse, then $X(k)=1$ (by definition) and hence $Y(k)$ will equal $H(k)$, the desired spreading filter characteristic.

In our application we wish to determine the actual input to the system (the back wall or a flaw) when we have observed the output of the spreading filter $Y(k)$. Consequently we must find a filter characteristic which, when multiplied by $Y(k)$, will yield $X(k)$. This filter is the inverse of the spreading filter $H(k)$ which we will denote by $I(k)=1/H(k)$. In practice, $I(k)$ will not be precisely the required filter for several reasons.

The spreading function is essentially low-pass in nature but the higher frequency components are required for good resolution. Merely boosting the high frequency components will not prove to be effective because of a hitherto unmentioned factor: noise. After the ultrasound is converted to electrical energy by the array elements, electrical noise (which has high frequency components) is superimposed on the signal that is eventually digitized. Hence, a compromise must be made between boosting the high frequencies and not allowing the noise to be increased beyond reasonable proportions. Due to this noise, the optimum image enhancement can not be obtained. The general attributes of the desired filter are known, however, and provide a starting point for experimentation.

The desired inverse filter characteristic should essentially have unity gain at the low frequencies which will allow a uniform portion of the back wall to be virtually unaffected. Over a certain range of medium frequencies, the filter response should be greater than unity which will act to increase the edge sharpness of the image. Experimentation will determine what frequencies should be boosted and to what degree. Above some higher cut-off frequency (also experimentally determined), the filter response must decrease to zero gain. This acts to remove the high frequency noise from the enhanced image.

At this point it is appropriate to mention that since this analysis is being done in the spatial frequency domain, it is necessary to obtain the DFT of the input (the samples of the back wall). A multiplication is then required, followed by an inverse DFT transformation. Although this is readily done by computer simulation on the VAX, it is less easily accomplished in hardware. Consequently an alternate solution, known as deconvolution, is more feasible from the hardware point of view.

If we look at a linear discrete system in the time domain (or, in our case, the spatial distribution domain), the output of the system $y(n)$ is calculated from a convolution of the input samples $x(n)$ and the system weighting sequence $h(n)$. This weighting sequence $h(n)$ is actually the inverse DFT of the system filter characteristic $H(k)$. Just as an experimental inverse filter $I(k)$ exists, an inverse weighting sequence $i(n)$ exists. The symbolic notation for this convolution is $y(n)=h(n)*x(n)$ where n is an index meaning the nth sample of the numerical sequence or vector. The discrete convolution operator (*) is defined below:

$$f(n) * g(n) = \sum_{k=-\infty}^{\infty} f(k)\, g(n-k)$$

This sum of products formula can be implemented quite easily in hardware. Consequently, using convolution (or "deconvolution" since the inverse weighting sequence is used) we can calculate the output sequence (literally the enhanced back wall itself) directly. Using this method we need only specify the inverse weighting sequence i(n) and the original back wall samples x(n).

8.2 HARDWARE

The proposed deconvolution board is an extremely powerful peripheral device to the LSI-11 Q-Bus. The primary function of the deconvolution board will be to perform the required multiplications and summations in a fraction of the time required by the LSI-11 for equivalent operations. Direct Memory Access (DMA) capability has been included on the board. This feature allows it to have random access to any memory on the LSI-11's Q-Bus without processor intervention. Consequently, with the proper microcode, the board can take control of the Q-Bus and execute flaw detection and framestore searching operations as well as deconvolution. In fact, if the board is programmed to its full capability, it can conceivably operate on the framestore more effectively than the LSI-11. The board has the capability of fetching its own instructions from memory, much like the master processor.

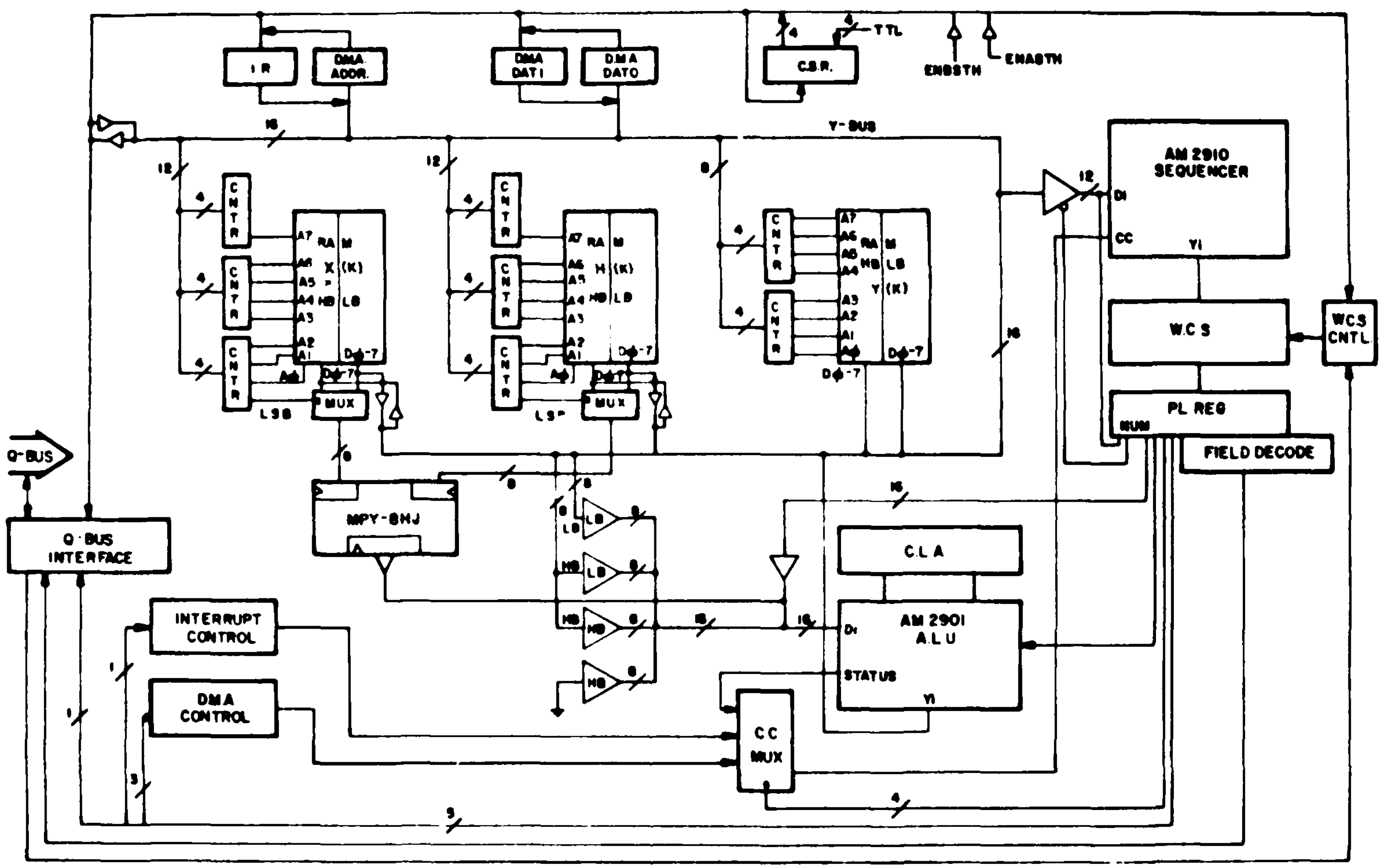
The primary architectural advantage of the hardware is that its control sequencing and arithmetic operations are based on Advanced Micro Devices' 2900 series family of bit-slice integrated circuits. AMD's

2900 series bit-slice architecture permits the design of a very versatile and powerful machine because its sequencing, decision-making, and arithmetic and control operations can be programmed with a design-dependent language called microcode. This microcode is stored in the board's writable control store memory. Microcode forms a "program" that determines the board's internal control and sequencing signals. Each instruction that is given to the board has an associated set of microinstructions that are executed.

As mentioned before, the board is very versatile. New modes of operation can be implemented by merely changing the microcode. Because the microcode is stored in read/write random access memory instead of read only memory, it can be modified from the system console or the flaw detection program. This allows the flaw analysis program to adaptively delegate varying responsibilities to the deconvolution board.

A diagram of the architecture is provided in figure 24. There are several subsystems on the board :

1) The AMD 2910 SEQUENCER controls all of the decision - making processes (condition code testing) and microprogram branching. It is this chip that generates the address to the microprogram memory and therefore determines the microinstuction to be executed next.



BIT-SLICE DECONVOLUTION LOGIC DIAGRAM

Figure 24

2) The WRITABLE CONTROL STORE is the microprogram memory. It is a 55 nanosecond access, 4K word by 72 bit static random access memory.

3) The WRITABLE CONTROL STORE CONTROL section controls the loading of the microprogram memory from the Q-Bus.

4) The AMD 2901 ALU is the arithmetic and logic unit for the board. It generates the 16-bit memory addresses for DMA and performs all the numerical and logical operations on the data.

5) The TRW MPY8-HJ is an 8-bit by 8-bit multiplier chip that multiplies the weighting sequence h(k) by the input sequence x(k). The multiplication can be done in only one board clock cycle which is approximately 80 times faster than the same operation on the LSI-11.

6) The H(K),Y(K) and X(K) RAM chips provide the on-board high speed data cache for the storage of the three sequences. The memories are large enough to allow four sequences to be stored in each.

7) The Q-BUS INTERFACE section contains the Q-BUS drivers and receivers, address decoders, and bus interface logic for software driven data transfers to and from the board. This interface section allows the programmer to have read/write access to the four

registers on the board as well as the three random access memory vectors.

8) The INTERRUPT CONTROL section is responsible for generating the Q-BUS signals that initiate a processor interrupt. The interrupt vector is fully programmable and is usually specified as one of the command string operands. Hence, one of several different interrupt service subroutines can be pointed to, depending on the particular function being performed by the board.

9) The DMA CONTROL section controls the LSI-11 Q-bus signals that are involved in requesting the bus and asserting bus mastership. Once bus mastership is attained, this section controls the Q-BUS timing for DMA data transfers to and from the board. Direct Memory Access allows blocks of data to be transferred from the framestore to the on-board cache at much higher rates than LSI-11 software loops would allow. DMA capability also allows the board to read or write data on its own initiative. This allows it to effectively fetch its own instructions.

8.3 DISCUSSION OF DECONVOLUTION

The only drawback to the deconvolution subsystem is the fact that the effects on the image will be severely limited in the presence of large amounts of noise. This system is inherently noisy and it is for this reason that the deconvolution board which has been discussed in this section could not be implemented.

PART 9

CONCLUSIONS

Implementation of a flaw detection system consisting of a commercially available medical ultrasonic system interfaced to an LSI11/03 has proved feasible. The advantages of this approach are the high degree of maintainability of the bulk of the system components, the low cost of the system due to limited requirements for new engineering, and the high processing throughput rate obtainable. However, due to the small aperture employed in typical commercial systems (usually only 16 elements are activated at any time out of the 256 in the array), and the constrained method of beam formation, the quality of flaw imaging obtainable is inadequate for precise flaw characterization or close flaw resolution. To correct this situation a second phase system specialized for image formation has been proposed. This system would not at first offer the high throughput rate possible with the simpler phase one detection system, but would offer a much larger aperture (simultaneously accessing all 256 elements), and a greater flexibility in signal processing. This second phase system would operate in tandem with the phase one system's high speed flaw detector, concentrating on regions where the phase one system locates a flaw. The phase two system will provide for a variety of imaging methods including focused simulated lens phase array techniques with dynamic focusing, pulse-echo weakly focused processing, and digital holography.

PART 10

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APPENDIX I

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; FLAW DETECTION AND IDENTIFICATION PROGRAM
; BENET WEAPONS LAB PROJECT  - R.P.I. MARCH 1982
; PROGRAMMED BY TOM CAVILEER
;      THIS PROGRAM IS WRITTEN IN MACRO11-RSX FOR USE
; ON THE PDP-11 WHICH PROVIDES THE CENTRAL PROCESSING
; CAPABILITY OF THE SYSTEM.  THE PROGRAM SERVES
; SEVERAL PURPOSES.  THE PROGRAM PROVIDES A MEANS OF
; OPERATOR CONTROL OF THE SYSTEM FUNCTIONS.  THE USER
; CAN ALTER VARIOUS GAINS AND PARAMETERS OF THE SEARLE
; IMAGING SYSTEM.  SUBROUTINES CONTROL THE DISPLAY OF
; INFORMATION ABOUT THE SYSTEM ON THE CRT TERMINAL AND
; THE SEARLE UNIT'S TELEVISION SCREEN.  FINALLY, THE
; ACTUAL WORK OF FLAW DETECTION WITHIN THE IMAGE IS
; DONE BY THE SYSTEM SOFTWARE.
;      THIS PROGRAM IS INTENDED AS THE CORE OF A
; LARGER SOFTWARE PACKAGE THAT WILL ACCOMMODATE CONTROL
; OF THE MECHANICAL MOVEMENTS OF THE SYSTEM AND THE
; STORAGE AND RETRIEVAL OF INFORMATION REGARDING THE
; LOCATION OF FLAWS.  THESE ADDITIONAL FUNCTIONS WILL
; BE INTEGRATED INTO THE SOFTWARE AS THE MECHANICAL
; HARDWARE INVOLVED IS COMPLETED.
; ARRAY AND FLAW LOCATION PROGRAM
;  PROGRAMMED BY RON BURGIN  DECEMBER 1982
;      THIS PROGRAM USES THE SOFTWARE DEVELOPED BY
; TOM CAVILEER.  THE LINE CLOCK INTERRUPT IS USED
; TO KEEP TRACK OF THE ROTATIONAL POSITION OF THE
; BILLET.  ON POWER UP THE ARRAY IS MOVED COMPLETELY
; TO THE RIGHT.  THE OPERATOR INPUTS THE DISPLACEMENT
; THAT HE WANTS TO START OFF AT AND THE LENGTH
; OF THE BILLET.  AFTER RECEIVING LEGAL
; RESPONSES, THE BILLET IS TIMED FOR FIVE ROTATIONS
; TO CALCULATE THE AMOUNT TO ADD PER LINE CLOCK
; INTERRUPT.  THE OPERATOR CAN THEN ALIGN THE ARRAY
; AND START THE SCAN.
;      WHEN THE SCAN IS COMPLETE THE PROGRAM REPORTS
; THE NUMBER OF FLAWS FOUND.  THE OPERATOR CAN THEN
; LOOK AT THE FLAW LOG TO GET AN IDEA OF WHERE THE
; FLAWS ARE.  TO SEE THE FLAWS, THE OPERATOR ENTERS
; THE FLAW NUMBER (GIVEN BY THE DISPLAY FLAW ROUTINE)
; AND THE FLAW WILL BE DISPLAYED.  BY PRESSING CERTAIN
; KEYS THE OPERATOR CAN MOVE THE ARRAY AND CHANGE THE
; ANGLE DESIRED, TO GET A BETTER VIEW OF THE FLAW.
;      THE SOFTWARE RESIDES ON EIGHT INTEL 2708 PROMS
; LOCATED ON A STANDARD DIGITAL BOARD.  THE PROGRAM
; CAN BE ADAPTED BY CHANGING A SINGLE LINE OF CODE INTO
; EITHER OF TWO CONFIGURATIONS. IF THE PROGRAM BEGINS
; WITH THE LINE: PROMS=0 ; THEN IT WILL BE ASSEMBLED
; AS CODE INTENDED FOR DOWNLOADING DIRECTLY TO THE
; RAM IN THE PDP-11.  THIS MODE IS USED FOR PROGRAM
; DEVELOPMENT, MODIFICATION, AND TESTING.  A PROGRAM
; READY FOR MORE PERMANENT STORAGE BEGINS WITH THE
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; LINE: PROMS=1 ; THIS WILL BE ASSEMBLED FOR THE PROMS
; WHICH ARE LOCATED AT LOCATION 0 IN THE COMPUTER'S
; MEMORY.
;      WHEN THE MACHINE IS POWERED UP, THE SOFTWARE
; BEGINS EXECUTION FROM THE PROMS.  THE FIRST OPERATION
; OF THE PROGRAM IS TO COPY ITSELF TO RAM.  THIS IS
; DONE TO INCREASE PROGRAM SPEED; SINCE THE INSTRUCTION
; FETCH TIME IS MUCH QUICKER FROM RAM THAN PROM.  THE
; PROGRAM THEN PASSES CONTROL TO THE APPROPRIATE POINT
; IN RAM AND BEGINS EXECUTION.
; THIS PROGRAM WILL ASSEMBLE FOR STORAGE IN PROGRAMMABLE
; READ-ONLY MEMORY.
PROMS=1
; SECTION 0. INTERRUPT VECTORS
;      THIS SECTION SETS UP THE INTERRUPT VECTORS AT
; THEIR PROPER LOCATIONS IN PROM. THE VECTORS AND THEIR
; LOCATIONS ARE AS FOLLOWS:
;   STRTPC=24       ;POWER UP PC
;   STRTPS=26       ;POWER UP PS
;   PRSTHV=200      ;INTERRUPT FROM PROBE RESET
;   STEPRV=300      ;INTERRUPT FROM STEPPER MOTOR
;   TERMRV=60       ;RECEIVE INTERRUPT FROM TERMINAL
;   TERMTV=64       ;TRANSMIT INTERRUPT TO TERMINAL
;   CLKINT=100      ;INTERRUPT FROM LINE CLOCK
        .IF NE PROMS
        .ASECT
FDS4:   .=0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
VSRTPC: .WORD   376
VSRTPS: .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
VTERMR: .WORD   420
        .WORD   0
```

```
VTERMT: .WORD   424
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
CLKINT: .WORD   CLKTIC                  ;LINE CLOCK
INTERRUPT
CLKPRI: .WORD   340                     ;LINE CLOCK
HAS PRIO=7
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
VPRSTH: .WORD   430
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
        .WORD   0
```

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                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
       VSTEPR:  .WORD   434
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   RXINT
                .WORD   200
                .WORD   TXINT
                .WORD   200
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
                .WORD   0
       ; SECTION 0-1. PROGRAM COPIES ITSELF TO RAM
       COPY:
                MOV      37760,R0      ;LOCATION IN RAM
```

```
        MOV     442,R1          ;LOCATION IN PROM
        MOV     10000,R5         ;WORD COUNT
S1L1:
        MOV     (R1)+,(RO)+     ;MOVE WORD TO RAM
        SOB     R5,S1L1         ;CONTINUE UNTIL COUNT=0
        JMP     40000           ;TRANSFER CONTROL TO RAM
; THESE JUMPS STEER THE PROGRAM TO THE PROPER INTERRUPT
; SERVICE SUBROUTINE.
        JMP     37760
        JMP     37762
        JMP     37764
        JMP     37766
        .ENDC
; SECTION 0-2. DOWNLOADED PROGRAM
;       IF THE PROGRAM IS INTENDED FOR DOWNLOADING, THIS
;    SECTION WILL ASSEMBLE IT FOR THE PROPER LOCATION.
        .IF EQ PROMS
        .ASECT
FDS5:   .=37760
        .ENDC
        JMP     IVECT1
        JMP     IVECT2
        JMP     IVECT3
        JMP     IVECT4
; SECTION 1. INITIALIZATIONS
;       THIS SECTION OF THE CODE INITIALIZES THE STACK,
; SYSTEM CONTROL PARAMETERS, DISPLAYS POWER UP
; VIA SUBROUTINE. IT ALSO CALLS A SUBROUTINE
; WHICH CLEARS BOTH SYSTEM FRAMESTORES.
INIT:   MOV     PSTACK,SP           ;PROGRAM STACK
        .IF EQ PROMS
        MOV     37760,@ TERMRV      ;CRT READ INTERRUPT
        MOV     37762,@ TERMTV      ;CRT WRITE INTERRUPT
        MOV     37764,@ PRSTHV      ;PROBE RESET HIGH
        MOV     37766,@ STEPRV      ;STEPPER MOTOR END
        MOV     CLKTIC,@ 100        ;CLOCK INTERRUPT
        MOV     340,@ 102
        .ENDC
        JSR     PC,POWERU           ;POWER UP
INSTRUCTIONS
        MOV     377,@ MTXBUF        ;MOVE MOTOR A LITTLE
        CLR     @ FRAMEA            ;FRAMEO ON QBUS
        JSR     PC,FSCLRP           ;CLEAR FRAMESTORE 0
        INC     @ FRAMEA            ;FRAME1 ON QBUS
        JSR     PC,FSCLRP           ;CLEAR FRAMESTORE 1
        MOV     1043,@ SRDLY        ;INIT. SR,DELAY
        MOV     2,@ NOISE           ;INIT. BACKGR. NOISE
        MOV     60,@ NOISE2         ;INIT. NOISE LEVEL
        MOVB    2,@ GAINS           ;INIT. GAINS
        MOVB    370,@ SLOPE         ;INIT. SLOPE
        MOV     605,@ GBUF          ;INIT. RXATTN,TXGAIN
        MOV     0,@ SHADOW          ;INIT. SHADOW THRHOLD
        CLR     @ QBUS              ;FRAMESTORE 0 ON QBUS
```

```
        MOV     1,@ DBUS            ;FRAMESTORE 1 ON DBUS
        JSR     PC,HOME             ;MOVE ARRAY ALL THE
WAY LEFT
        JSR     PC,GETLAR           ;GET DISPMENT AND
LENGTH
        MOV     1,@ CFLAG           ;SET CFLAG FOR
COMPLETE FLAW DECTION
        CLR     @ KFLAG             ;RESET KEYBOARD
SENSITIVE FLAG
 CLR      @ ROW2             ;THIS IS THE POINTER TO THE
BOTTOM
;OF THE BACKWALL.  IF ON THE FIRST ATTEMPT AT FLAW
DETECTION THE
;BACKWALL IS NOT FOUND AND A LARGE NUMBER IS LEFT IN
THIS LOCATION
;THE SUBROUTINE CLEAN WILL TRY TO ACCESS NON-EXISTENT
MEMORY. THIS WILL
;KILL THE SOFTWARE, AND THEREFORE MUST BE CLEARED.
; SECTION 2. MAIN MENU ROUTINES
; THIS SECTION HANDLES THE THREE MAIN MENUS. FOR
; EACH MENU THE CHOICES ARE DISPLAYED AND THEN
; WAITS FOR THE OPERATOR TO RESPOND. AN ILLEGAL
; RESPONSE IS IGNORED.
; FIRST MENU
COMMN1:
        MOV     DINIT1,RO       ;LOC. OF MESSAGE->RO
        JSR     PC,OUTPUT        ;MESSAGE TO CRT
        MOVB    @ DBUS,RO        ;FRAMESTORE   --> RO
        JSR     PC,ONUM2         ;SHOW FRAMESTORE
        MOV     DINIT2,RO       ;LOC. OF MESSAGE->RO
        JSR     PC,OUTPUT        ;MESSAGE TO CRT
; PLACE COMMAND CHOICES ON THE SCREEN
        MOV     CMESS1,RO       ;LOCATION OF MESSAGE
        JSR     PC,OUTPUT        ;MESSAGE TO TERMINAL
; TAKE COMMAND FROM USER
S2L2:   TSTB    @ TRDCSR            ;TEST FOR KEYSTROKE
        BPL     S2L2                ;WAIT FOR KEYSTROKE
INCHR:  MOVB    @ TRDBUF,R1         ;ACCEPT USER INPUT
; TEST CHARACTER AND BRANCH TO APPROPRIATE ROUTINE
TESTC:  BIC     177600,R1           ;CLEAR NON ASCII BITS
        CMP     R1, 123             ;S PRESSED ?
        BEQ     PARAMJ              ;SET PRAMS
        CMP     R1, 120             ;P PRESSED ?
        BEQ     PROBEJ              ;PROBE
        CMP     R1, 103             ;C PRESSED?
        BEQ     FSCLJ1              ;FRAMESTORE CLEAR
        CMP     R1, 104             ;D PRESSED?
        BEQ     DFJ1                ;SWITCH FRAME STORES
        CMP     R1, 115             ;M PRESSED?
        BEQ     COMMN3              ;EXTRA ROUTINES
        CMP     R1, 106             ;F PRESSED?
        BEQ     SCANJ               ;FIND FLAWS
        CMP     R1, 121             ;Q PRESSED?
```

```
        BEQ     POWRDJ                  ;POWER DOWN
        JMP     COMMN1
PARAMJ: JMP     PARAMS
PROBEJ: JMP     PROBE
FSCLJ1: JSR     PC,FSCLR
        JMP     COMMN1
DFJ1:   JSR     PC,DF
        JMP     COMMN1
SCANJ:  JMP     SCAN
POWRDJ: JSR     PC,POWERD
        JMP     COMMN1
;
;THE SECOND MENU
;
COMMN2: MOV     MENU2,R0               ;DISPLAY THE MENU
        JSR    PC,OUTPUT
COMW2:  TSTB   @ TRDCSR                 ;AWAIT OPERATOR REPLY
        BPL    COMW2
        MOV    @ TRDBUF,R1              ;GET RESPONSE
        BIC     177600,R1               ;CLEAR UPPER BYTE
        CMP     R1, 123                 ;S PRESSED ?
        BEQ     DLOGJ                   ;DISPLAY LOG
        CMP     R1, 103                 ;C PRESSED?
        BEQ     FSCLJ2                  ;FRAMESTORE CLEAR
        CMP     R1, 104                 ;D PRESSED?
        BEQ     DFJ2                    ;SWITCH FRAME STORES
        CMP     R1, 115                 ;M PRESSED?
        BEQ     COMMN3                  ;EXTRA ROUTINES
        CMP     R1, 121                 ;Q PRESSED?
        BEQ     POWRJ2                  ;POWER DOWN
        CMP     R1, 114                 ;L PRESSED?
        BEQ     LOCJ                    ;LOCATE FLAWS
        JMP     COMMN2                  ;IGNORE RESPONSE
DLOGJ:  JMP     DLOG
LOCJ:   JMP     LOCATE
DFJ2:   JSR     PC,DF
        JMP     COMMN2
POWRJ2: JSR     PC,POWERD
        JMP     COMMN2
FSCLJ2: JSR     PC,FSCLR
        JMP     COMMN2
;
;COMMN3 EXTRA ROUTINES
;       THIS IS THE THIRD MENU
; IT INCLUDES ROUTINES WHICH MAY BE USEFUL TO THE
OPERATOR
; BUT AREN'T NECESSARY TO DO THE BILLET SCANNING. I.E.
; REPEATED FLAW DETECTION COULD AID IN SETTING THE
PARAMETERS
;
COMMN3: MOV     MENU3,R0               ;DISPLAY THE MENU
        JSR    PC,OUTPUT
COMW3:  TSTB   @ TRDCSR                 ;WAIT FOR A RESPONSE
```

```
            BPL     COMW3
            MOV     @ TRDBUF,R1         ;GET RESPONSE
            BIC      177600,R1          ;CLEAR UPPER BYTE
            CMP      R1, 103            ;C PRESSED?
            BEQ      SSFJ               ;SINGLE SHOT FLAW DECT
            CMP      R1, 104            ;D PRESSED?
            BEQ      RFDJ               ;REPEATED FLAW DECT
            CMP      R1, 106            ;F PRESSED?
            BNE      COM3               ;NO
            JMP      COMMN1             ;EXIT TO FIRST MENU
COM3:       CMP      R1, 123            ;S PRESSED?
            BNE      COM3B              ;NO
            JMP      COMMN2             ;EXIT TO SECOND MENU
COM3B:      CMP      R1, 121            ;Q PRESSED?
            BEQ      POWRJ3             ;POWER DOWN
            CMP      R1, 125            ;U PRESSED?
            BEQ      UPJ                ;UPLOAD FRAME STORE
            CMP      R1, 110            ;H PRESSED
            BNE      COMMN3             ;NO
            JSR      PC,HOMEA           ;HOME AGAIN
            BR       COMMN3
SSFJ:       JMP      GO
RFDJ:       JMP      REPEAT
UPJ:        JMP      UPLOAD
POWRJ3:     JSR      PC,POWERD
            JMP      COMMN3
; SECTION 2-1.  COMMAND ROUTINES
;      IN DEVELOPING THIS PROGRAM, FLEXIBILITY WAS A
; MAJOR CONSIDERATION.  BECAUSE I WANTED TO HAVE THE
; ABILITY TO ADD NEW SECTIONS AS THEY BECAME AVAILABLE,
; I DECIDED TO USE COMMAND ROUTINES TO CONTROL THE
; EXECUTION OF SUBROUTINES.  THUS A NEW SUBROUTINE CAN
; BE ADDED WITHOUT CHANGING EXISTING WORKING ROUTINES.
; THIS SECTION CONSISTS OF THESE CONTROL ROUTINES.
; ALSO, THE SAME ROUTINES CAN BE USED IN SINGLE-SHOT
; OR REPEATED EXECUTION MODE

; PARAMS CONTROLS THE SETTING OF PARAMETERS USING THE
; TERMINAL.
PARAMS:
            JSR      PC,PCHANG     ;SET PARAMETERS SUBROUTINE
            JMP      COMMN1        ;RETURN
; GO TAKES A SINGLE FRAME AND ANALYZES IT FOR FLAWS.
GO:
            MOV       1,@ CFLAG
            MOV     @ QBUS,@ FRAMEA     ;FILL FRAMESTORE
            MOV     @ DBUS,@ FRAMEB     ;ANALYZE FRAMESTORE
            JSR      PC,SAMPLE          ;TAKE SAMPLE
            JSR      PC,FLAWDP          ;SEARCH FOR FLAWS
            JSR      PC,CLEAN           ;CLEAN UP PICTURE
BELOW BACKWALL
            MOV     @ QBUS,@ FRAMEB     ;SHOW RESULT
            JSR      PC,DISPLY          ;DISPLAY ON TV SCREEN
```

```
        JMP     COMMN3                  ;RETURN
; PROBE PROVIDES A TV GRAPH OF THE BACKWALL
; ILLUMINATION FUNCTION.
PROBE:
        CLRB    @ FLAG2
PROBE1: MOV     @ QBUS,@ FRAMEA  ;FRAME ON QBUS
        MOV     @ DBUS,@ FRAMEB
        JSR     PC,SAMPLE       ;TAKE SAMPLE
        JSR     PC,ILLUM        ;ILLUMINATION SUBROUTINE
; FLIP THE FRAMESTORE ON THE DBUS TO THE QBUS; AND THE
; FRAMESTORE ON THE QBUS TO THE DBUS.
FLIP:   TST     @ QBUS
        BEQ     S3P1
        CLR     @ QBUS
        INC     @ DBUS
        BR      S3P2
S3P1:   INC     @ QBUS
        CLR     @ DBUS
; CONTINUE EXECUTING THESE ROUTINES UNTIL NEW COMMAND
; IS ENTERED.
S3P2:   TSTB    @ TRDCSR            ;TEST FOR KEYSTROKE
        BPL     PROBE1              ;REPEAT UNTIL KEYSTRK
        MOVB    @ TRDBUF,@ CMDCHR ;DISPOSE OF CHAR.
        JMP     INCHR               ;ON COMMAND, RETURN
; REPEAT PROVIDES FOR CONTINUOUS FLAW DETECTION;
; IT IS TERMINATED BY A NEW COMMAND FROM THE USER.
REPEAT:
        MOV      1,@ CFLAG
        MOV     @ QBUS,@ FRAMEA
        MOV     @ DBUS.@ FRAMEB
        JSR     PC,SAMPLE
        JSR     PC,FLAWDP
        JSR     PC,CLEAN
FLIP4:  TST     @ QBUS
        BEQ     S3P41
        CLR     @ QBUS
        INC     @ DBUS
        BR      S3P42
S3P41:  INC     @ QBUS
        CLR     @ DBUS
S3P42:  TSTB    @ TRDCSR     ;TEST FOR KEYSTROKE
        BPL     REPEAT       ;REPEAT UNTIL KEYSTROKE
        JMP     COMMN3       ;RETURN
; FSCLR CONTROLS THE CLEARING OF EITHER OF THE FRAME-
; STORES.
FSCLR:
        MOV     @ DBUS,@ FRAMEA     ;CLEAR FRAME
        MOV     @ QBUS,@ FRAMEB     ;DISPLAY FRAME
        JSR     PC,FSCLRP           ;CLEAR FRAMESTORE
        RTS     PC
; DF CONTROLS THE DISPLAY OF EITHER FRAMESTORE ON THE
; TV SCREEN AT THE USER'S COMMAND.
DF:
```

```
        JSR     PC,DFRAME
        RTS     PC
; SECTION 4.  SAMPLE ROUTINE / DISPLAY ROUTINE
;      THE SUBROUTINE SAMPLE IS USED TO TAKE AN IMAGE
; WITH THE SEARLE IMAGER.  THE INPUT PARAMETER FRAMEA
; TELLS WHICH FRAMESTORE TO PLACE ON THE QBUS DURING
; THE READ.  THE INPUT PARAMETER FRAMEB TELLS THE
; SUBROUTINE WHICH FRAMESTORE TO PLACE ON THE QBUS
; AFTER THE IMAGE IS READ.
;      FOR EXAMPLE IF FRAMEA=0 AND FRAMEB=1
; THEN ON COMPLETION FRAMESTORE 0 WILL HAVE
; THE NEW DATA AND FRAMESTORE 1 WILL BE DISPLAYED.
;      THE SUBSECTION OF SUBROUTINE BEGINNING WITH
; DISPLY: IS USED AS AN INDEPENDENT SUBROUTINE TO
; DISPLAY ONE OF THE FRAMESTORES AT USER COMMAND.
SAMPLE:
        MOV     @ SRDLY,@ ISRDLY ;LOAD IMAGER REGISTERS
        MOV     @ RAMPS,@ IRAMPS
        MOV     @ GBUF,@ IGAINS
S4L0:   TSTB    @ ICSR          ;CHECK FOR PRSTH LOW
        BMI     S4L0
S4L1:   TSTB    @ ICSR          ;WAIT FOR PRSTH
        BPL     S4L1
INTS1:  MOVB    @ FRAMEA,@ ICSR  ;CONNECT BUSSES
        BIS      2,@ ICSR      ;FRAMESTORE WRITE ENABLED
DISPLY:
        TSTB    @ ICSR          ;WAIT FOR PRSTH LOW
        BMI     DISPLY
S4L2:   TSTB    @ ICSR          ;WAIT FOR PRSTH
        BPL     S4L2
INTS2:  MOVB    @ FRAMEB,@ ICSR  ;CONNECT BUSSES
        BIC      400,@ ICSR     ;DISABLE INTERRUPT
        RTS     PC              ;RETURN
; SECTION 5. ILLUMINATION FUNCTION DISPLAY ROUTINE
;      THIS SUBROUTINE DISPLAYS A GRAPH OF THE BACKWALL
; ILLUMINATION FUNCTION ON THE TV SCREEN.  THE SUB-
; ROUTINE SEARCH IS USED TO FIND THE BACKWALL.  THE
; SUBROUTINE DISPLAYS THE ROW NUMBERS WHERE THE
; BACKWALL HAS BEEN FOUND ON THE CRT.  IF THE WALL
; IS NOT FOUND, A FLAG IS SET AND THE ROUTINE RETURNS
; CONTROL TO THE COMMAND ROUTINE WHICH CALLED IT.
ILLUM:
        JSR     PC,SEARCH    ;LOCATE BACKWALL
        TSTB    @ FLAG1      ;DID SEARCH FIND BACKWALL?
        BEQ     PATCH        ;IF NOT, RETURN
        RTS     PC
; THIS SECTION OF CODE UPDATES THE ROW NUMBER DISPLAY
; ON THE CRT.  ON THE FIRST PASS, HOWEVER, THE CODE
; ALSO CREATES THE MESSAGE TELLING THE USER WHERE THE
; FRAMESTORE HAS BEEN FOUND.  BY ONLY WRITING THIS TEXT
; ONCE, FASTER OPERATION IN REPEATED MODE IS ATTAINED.
PATCH:
        TSTB    @ FLAG2      ;FIRST PASS?
```

```
        BEQ     S5P20        ;IF SO, WRITE TEXT
; ON MOST PASSES, JUST UPDATE THE ROW NUMBERS
        MOV      BMESS3,R0   ;POSITION CURSOR
        JSR     PC,OUTPUT
        MOVB    @ ROW1,R0     ;LOAD TOP OF WALL ROW
        JSR     PC,ONUM2      ;SHOW ROW NUMBER
        MOV      BMESS4,R0   ;POSITION CURSOR
        JSR     PC,OUTPUT
        MOVB    @ ROW2,R0     ;LOAD BOTTOM OF WALL ROW
        JSR     PC,ONUM2      ;SHOW ROW NUMBER
        JMP     S5P21         ;DRAW GRAPH
; ON FIRST PASS, CLEAR SCREEN AND WRITE TEXT
S5P20:  MOV      WIPE,R0     ;CLEAR MESSAGE AREA
        JSR     PC,OUTPUT
        MOV      BMESS1,R0   ;LOAD LOC. OF MESSAGE
        JSR     PC,OUTPUT     ;OUTPUT TEXT
        MOVB    @ ROW1,R0     ;LOAD TOP OF WALL ROW
        JSR     PC,ONUM2      ;SHOW ROW NUMBER
        MOV      BMESS2,R0   ;LOAD LOC. OF MESSAGE
        JSR     PC,OUTPUT     ;OUTPUT TEXT
        MOVB    @ ROW2,R0     ;LOAD TOP OF WALL ROW
        JSR     PC,ONUM2      ;SHOW ROW NUMBER
        MOVB     1,@ FLAG2    ;SET FIRST PASS FLAG
; PUT GRAPH ON SCREEN
S5P21:
        JSR     PC,SUMMER ;SUM OVER BACKWALL IN COLUMN
        JSR     PC,SMOOTH ;AVERAGE ACROSS COLUMNS
        MOV      60000,R0 ;R0=COLUMN POINTER
        MOV      166,R5   ;R5 -- COLUMN COUNTER
        CLR     R2        ;BACKWALL VECTOR INDEX
S5L6:
        MOV     R0,R1     ;LOAD UP POINTER
        MOV      200,R4   ;NUMBER OF ROWS IN COLUMN
S5L8:
        CLR     (R1)+     ;CLEAR COLUMN
        SOB     R4,S5L8
        MOV     SMTHBW(R2),R3 ;TAKE DATA FROM VECTOR
        ASR     R3            ;SCALE R3 TO TV OUTPUT
        ASR     R3
        NEG     R3
        ADD      300,R3
        ADD     R0,R3    ;MOVE TO CORRECT COLUMN
        MOVB     77,(R3) ;PLACE DOT AT CORRECT POINT

        ADD      400,R0  ;MOVE TO NEXT COLUMN
        ADD      2,R2    ;INCREMENT VECTOR INDEX
        SOB     R5,S5L6  ;REPEAT FOR OTHER ROWS
        RTS     PC       ;RETURN
; SECTION 6. CLEAR FRAMESTORE ROUTINE
;      THIS SUBROUTINE CLEARS ONE OF THE FRAMESTORES.
; THE FRAME CLEARED WILL BE THE COMPLEMENT OF FRAMEA
; FRAMEB WILL BE THE DISPLAYED FRAME.
FSCLRP: MOV      60000,R0  ;INITIALIZE POINTER
```

```
        MOV     40000,R5   ;NUMBER OF WORDS IN FSTORE
S6L0:   TSTB    @ ICSR     ;CHECK FOR PRSTH LOW
        BMI     S6L0
S6L2:   TSTB    @ ICSR     ;WAIT FOR PRSTH
        BPL     S6L2
        MOVB    @ FRAMEA,@ ICSR    ;PUT OTHER FRAME ON
D-BUS
S6L1:
        CLR     (R0)+              ;CLEAR EACH WORD
        SOB     R5,S6L1            ;LOOP UNTIL COUNT=0
S6L3:
        TSTB    @ ICSR             ;CHECK FOR PRSTH LOW
        BMI     S6L3
S6L4:   TSTB    @ ICSR             ;WAIT FOR PRSTH
        BPL     S6L4
        MOVB    @ FRAMEB,@ ICSR    ;DISPLAY FRAMESTORE
        RTS     PC                 ;RETURN
; SECTION 7. PARAMETER CHANGE ROUTINE
;      THIS SUBROUTINE ALLOWS THE USER TO ALTER PROGRAM
; THRESHOLDS.
; THIS SECTION OF PCHANG PRINTS THE USER PROMPT.  THE
; CURRENT VALUES OF THE PARAMETERS ARE LISTED NEXT TO
; THE PARAMETER NAME.
PCHANG:
        MOV     CMESS2,R0  ;LOAD MESSAGE LOCATION
        JSR     PC,OUTPUT   ;PROMPT USER
        MOVB    @ SRATE,R0  ;CURRENT SAMPLING RATE
        JSR     PC,OUTNUM
        MOV     CMESS3,R0  ;DISPLAY TRANSMIT GAIN
        JSR     PC,OUTPUT
        MOVB    @ TXGAIN,R0
        CLC
        ROL     R0
        JSR     PC,OUTNUM
        MOV     CMESS4,R0  ;DISPLAY DELAY
        JSR     PC,OUTPUT
        MOVB    @ DELAY,R0
        JSR     PC,OUTNUM
        MOV     CMESS5,R0  ;DISPLAY NEAR GAIN
        JSR     PC,OUTPUT
        MOVB    @ GAINS,R0
        JSR     PC,OUTNUM
        MOV     CMESS7,R0  ;DISPLAY SLOPE GAIN
        JSR     PC,OUTPUT
        MOVB    @ SLOPE,R0
        BIC     200,R0      ;CLEAR ENABLE BIT
        JSR     PC,OUTNUM
        MOV     CMESS8,R0  ;DISPLAY ATTENUATION
        JSR     PC,OUTPUT
        MOVB    @ RXATTN,R0
        JSR     PC,OUTNUM
        MOV     CMESS9,R0  ;DISPLAY NOISE THRESHOLD
        JSR     PC,OUTPUT
```

```
        MOVB    @ NOISE,R0
        JSR     PC,OUTNUM
        MOV      CMESS0,R0  ;DISPLAY SHADOW THRESHOLD
        JSR     PC,OUTPUT
        MOVB    @ SHADOW,R0
        JSR     PC,OUTNUM
; NOW WE WAIT FOR THE USER TO ENTER A NUMBER OR RETURN.
; IF HE RETURNS, CONTROL IS TRANSFERRED TO THE COMMAND
; ROUTINE.  IF A NUMBER IS ENTERED, IT IS USED TO CALL
; THE CORRECT PARAMETER FOR CHANGE.
S7L2:   TSTB    @ TRDCSR             ;TEST FOR KEYSTROKE
        BPL     S7L2                 ;WAIT FOR KEYSTROKE
        MOVB    @ TRDBUF,@ CMDCHR ;ACCEPT USER INPUT
        BIC      177600,@ CMDCHR  ;TRIM TO 7-BIT ASCII
        CMPB    @ CMDCHR, CR         ;TEST FOR <CR>
        BNE     S7P1             ;ON OTHER INPUT, CONTINUE
        RTS     PC                   ;ON <CR>, RETURN
S7P1:
        CMPB    @ CMDCHR, 111     ;TEST FOR ILLEGAL CHAR.
        BPL     S7ERR1            ;PRINT ERROR IF ILLEGAL
        CMPB    @ CMDCHR, 101     ;TEST FOR ILLEGAL CHAR.
        BMI     S7ERR1            ;PRINT ERROR IF ILLEGAL
        BIC      177740,@ CMDCHR ;REDUCE CHARACTER
        MOV     @ CMDCHR,R0     ;LOCATION OF COMMAND LIST
        CLC
        ROL     R0                ;ADJUST TO WORD LENGTH
        ADD     @ S7LIST,R0       ;R0 NOW POINTER TO LIST
        MOV     (R0),R1
        JMP     (R1)          ;BRANCH TO ROUTINE SELECTED
; PRINT ERROR MESSAGE IF ILLEGAL CHARACTER ENTERED.
S7ERR1: MOV      WIPE,R0      ;CLEAR MESSAGE AREA
        JSR     PC,OUTPUT
        MOV      EMESS2,R0  ;LOC. OF ERROR MESSAGE
        JSR     PC,OUTPUT     ;PRINT MESSAGE
        JMP     S7L2
; THIS SECTION CONTAINS THE SUBROUTINES WHICH ALTER THE
; VARIOUS PARAMETERS.  EACH IS HANDLED IN AN
; INDEPENDENT ROUTINE SO THAT DIFFERENT MANIPULATIONS
; CAN BE USED TO PUT THE DECIMAL VALUE INTO THE
; REQUIRED FORMAT FOR USE BY THE PROGRAM.
S7AAAA:
        MOV      WIPE,R0        ;CLEAR SCREEN
        JSR     PC,OUTPUT
        MOV      PMESSA,R0      ;LOCATION OF MESSAGE
        JSR     PC,OUTPUT        ;PROMPT USER
        MOVB    @ SRATE,R0       ;CURRENT SAMPLING RATE
        MOV     R0,-(SP)         ;PUSH SAMPLING RATE
        JSR     PC,OUTNUM        ;DISPLAY CURRENT VALUE
        MOV     (SP)+,R3         ;R3 = CURRENT VALUE
        JSR     PC,INNUM         ;RETRIEVE USER CHANGE
        MOVB    R3,@ SRATE       ;STORE CHANGE
        JMP     PCHANG           ;RETURN
S7BBBB:
```

```
          MOV     WIPE,RO        ;CLEAR SCREEN
          JSR     PC,OUTPUT
          MOV     PMESSB,RO      ;LOCATION OF MESSAGE
          JSR     PC,OUTPUT       ;PROMPT USER
          MOVB    @ TXGAIN,RO     ;CURRENT TRANSMIT GAIN
          CLC
          ROL     RO
          MOV     RO,-(SP)        ;PUSH TRANSMIT GAIN
          JSR     PC,OUTNUM       ;DISPLAY CURRENT VALUE
          MOV     (SP)+,R3        ;R3 = CURRENT VALUE
          JSR     PC,INNUM        ;RETRIEVE USER CHANGE
          ASR     R3              ;DIVIDE BY TWO TO SCALE
          MOVB    R3,@ TXGAIN     ;STORE CHANGE
          BEQ     S7BBB1          ;IF INPUT=0 THEN DON'T
SET ENABLE BIT
          BISB    200,@ TXGAIN    ;SET THE ENABLE BIT
S7BBB1:   JMP     PCHANG          ;RETURN
S7CCCC:
          MOV     WIPE,RO        ;CLEAR SCREEN
          JSR     PC,OUTPUT
          MOV     PMESSC,RO      ;LOCATION OF MESSAGE
          JSR     PC,OUTPUT       ;PROMPT USER
          MOVB    @ DELAY,RO      ;CURRENT DELAY
          MOV     RO,-(SP)        ;PUSH CURRENT DELAY
          JSR     PC,OUTNUM       ;DISPLAY CURRENT VALUE
          MOV     (SP)+,R3        ;R3 = CURRENT VALUE
          JSR     PC,INNUM        ;RETRIEVE USER CHANGE
          MOVB    R3,@ DELAY      ;STORE CHANGE
          JMP     PCHANG          ;RETURN
S7DDDD:
          MOV     WIPE,RO        ;CLEAR SCREEN
          JSR     PC,OUTPUT
          MOV     PMESSD,RO      ;LOCATION OF MESSAGE
          JSR     PC,OUTPUT       ;PROMPT USER
          MOVB    @ GAINS,RO      ;CURRENT VALUE OF GAINS
          MOV     RO,-(SP)        ;PUSH CURRENT GAINS
          JSR     PC,OUTNUM       ;DISPLAY CURRENT VALUE
          MOV     (SP)+,R3        ;R3 = CURRENT VALUE
          JSR     PC,INNUM        ;RETRIEVE USER CHANGE
          MOVB    R3,@ GAINS      ;STORE NEW GAIN VALUE
          JMP     PCHANG          ;RETURN
S7EEEE:
          MOV     WIPE,RO        ;CLEAR SCREEN
          JSR     PC,OUTPUT
          MOV     PMESSF,RO      ;LOCATION OF MESSAGE
          JSR     PC,OUTPUT       ;PROMPT USER
          MOVB    @ SLOPE,RO      ;CURRENT RAMP SLOPE
          BICB    200,RO          ;CLEAR ENABLE BIT TO GET
CORRECT NUMBER
          MOV     RO,-(SP)        ;PUSH CURRENT SLOPE
          JSR     PC,OUTNUM       ;DISPLAY CURRENT VALUE
          MOV     (SP)+,R3        ;R3 = CURRENT VALUE
          JSR     PC,INNUM        ;RETRIEVE USER CHANGE
```

```
        MOVB    R3,@ SLOPE       ;STORE NEW SLOPE VALUE
        BEQ     S7EEE1           ;IF ZERO THEN DON'T SET
ENABLE BIT
        BISB     200,@ SLOPE     ;SET ENABLE BIT
S7EEE1: JMP     PCHANG           ;RETURN
S7FFFF:
        MOV      WIPE,R0        ;CLEAR SCREEN
        JSR     PC,OUTPUT
        MOV      PMESSG,R0      ;LOCATION OF MESSAGE
        JSR     PC,OUTPUT        ;PROMPT USER
        MOVB    @ RXATTN,R0      ;CURRENT ATTENUATION
        MOV     R0,-(SP)         ;PUSH CURRENT RXATTN
        JSR     PC,OUTNUM        ;DISPLAY CURRENT VALUE
        MOV     (SP)+,R3         ;R3 = CURRENT VALUE
        JSR     PC,INNUM         ;RETRIEVE USER CHANGE
        TST     R3
        BEQ     S7FFF1
        MOVB     1,@ RXATTN      ;SET TO 1
        JMP     PCHANG           ;RETURN
S7FFF1: CLRB    @ RXATTN         ;SET TO 0
        JMP     PCHANG
S7GGGG:
        MOV      WIPE,R0        ;CLEAR SCREEN
        JSR     PC,OUTPUT
        MOV      PMESSH,R0      ;LOCATION OF MESSAGE
        JSR     PC,OUTPUT        ;PROMPT USER
        MOVB    @ NOISE,R0       ;CURRENT NOISE SETTING
        MOV     R0,-(SP)         ;PUSH CURRENT NOISE
SETTING
        JSR     PC,OUTNUM        ;DISPLAY CURRENT VALUE
        MOV     (SP)+,R3         ;R3 = CURRENT VALUE
        JSR     PC,INNUM         ;RETRIEVE USER CHANGE
        MOVB    R3,@ NOISE       ;STORE CHANGE
        JMP     PCHANG           ;RETURN
S7HHHH:
        MOV      WIPE,R0        ;CLEAR SCREEN
        JSR     PC,OUTPUT
        MOV      PMESSI,R0      ;LOCATION OF MESSAGE
        JSR     PC,OUTPUT        ;PROMPT USER
        MOVB    @ SHADOW,R0      ;CURRENT SHADOW
THRESHOLD
        MOV     R0,-(SP)         ;PUSH CURRENT THRESHOLD
        JSR     PC,OUTNUM        ;DISPLAY CURRENT VALUE
        MOV     (SP)+,R3         ;R3 = CURRENT VALUE
        JSR     PC,INNUM         ;RETRIEVE USER CHANGE
        MOVB    R3,@ SHADOW      ;STORE CHANGE
        JMP     PCHANG           ;RETURN
; SECTION 8. I/O SUBROUTINES
; SECTION 8-1. SUBROUTINE OUTNUM
; PRINTS ONE BYTE WITHIN PARENTHESES ON THE TERMINAL
OUTNUM:
        BIC      177400,R0    ;TAKE CARE OF HIGH BYTE
        MOV      NUMBUF,R1    ;OUTPUT BUFFER LOCATION
```

```
        MOVB    LEFTP,(R1)+  ;LEFT PARENTHESIS
        CLR     R3           ;WORKING REGISTER
        CLR     R4           ;WORKING REGISTER
        MOV     R0,R2        ;NUMBER --> R2
; PERFORM OCTAL TO DECIMAL CONVERSION.
S7L3:   SUB     144,R2
        BMI     S7P4
        INC     R3
        MOV     R2,R0
        BR      S7L3
S7P4:   MOV     R0,R2
S7L4:   SUB     12,R2
        BMI     S7P5
        INC     R4
        MOV     R2,R0
        BR      S7L4
; CONVERT EACH DIGIT TO AN ASCII CHARACTER.
S7P5:   ADD     260,R3
        MOVB    R3,(R1)+     ;LOAD INTO OUTPUT BUFFER
        ADD     260,R4
        MOVB    R4,(R1)+     ;LOAD INTO OUTPUT BUFFER
        ADD     260,R0
        MOVB    R0,(R1)+     ;LOAD INTO OUTPUT BUFFER
        MOVB    RIGHTP,(R1)+       ;RIGHT PARENTHESIS
        MOVB    SPACE,(R1)+        ;SPACE
        CLRB    (R1)               ;TRAILING ZERO
        MOV     NUMBUF,R0          ;LOCATION OF BUFFER
        JSR     PC,OUTPUT          ;NUMBER TO TERMINAL
        RTS     PC                 ;RETURN
; SECTION 8-2. SUBROUTINE INNUM
; TAKES USER NUMBER FROM THE TERMINAL INTO A BYTE.
; IT CHECKS FOR A LEGAL RESPONSE.
INNUM:
        CLR     R1
        CLR     R2
        CLR     @ MANUAL
;
; TAKE FIRST INPUT CHARACTER
;
CHAR1:  TSTB    @ TRDCSR
        BPL     CHAR1
        MOVB    @ TRDBUF,R1       ;CHAR. ENTERED BY USER
        MOVB    R1,@ TTXBUF       ;ECHO
        BIC     177600,R1
        CMPB    R1, 15            ;USER RETURNS TO IGNORE
        BEQ     GOBACK
        CMPB    R1, 115           ;MANUAL SETTING
        BNE     S7P101
        MOV     1,@ MANUAL
        RTS     PC
S7P101:
        CLR     R3                ;OUTPUT REGISTER
;
```

```
; PROCESS EACH CHARACTER
;
PRCESS: SUB     60,R1
        BMI    ILLNUM
        CMP     11,R1
        BLT    ILLNUM
        CLC
        ROL    R2          ;MULT. PREVIOUS RESULT BY 2
        ROL    R3
        ROL    R3          ;MULT. PREVIOUS RESULT BY 8
        ROL    R3
        ADD    R2,R3       ;PREVIOUS RESULT TIMES 10
        ADD    R1,R3       ;ADD NEW LOW ORDER DIGIT
        MOV    R3,R2       ;R2,R3 = PREVIOUS RESULT
;
; INPUT SUCCEEDING CHARACTERS
;
CHARN:  TSTB   @ TRDCSR          ;WAIT FOR USER INPUT
        BPL    CHARN
        MOVB   @ TRDBUF,R1       ;CHAR. ENTERED BY USER
        MOVB   R1,@ TTXBUF       ;ECHO
        BIC     177600,R1        ;LIMIT TO 7 BITS
        CMPB   R1, 15            ;TEST FOR RETURN
        BNE    PRCESS
GOBACK: RTS    PC
ILLNUM: MOV     ILNUM,R0
        JSR    PC,OUTPUT
        JMP    INNUM
S7LIST: .WORD   S7LIST
        .WORD   S7AAAA
        .WORD   S7BBBB
        .WORD   S7CCCC
        .WORD   S7DDDD
        .WORD   S7EEEE
        .WORD   S7FFFF
        .WORD   S7GGGG
        .WORD   S7HHHH
; SECTION 8-3.
; ONUM2 - OUTPUTS ONE BYTE WITHOUT THE PARENTHESIS.
; ONUM3 - OUTPUTS UP TO 999 WITHOUT BLANKS AND NO
;         LEADING ZERO IN HUNDREDS PLACE.
; NFLAG TELLS WHICH MODE TO USE =0 THEN ONUM3 ELSE
ONUM2
ONUM3:  CLR     @ NFLAG         ;SELECT MODE
        MOV      NUMBUF,R1      ;SET UP BUFFER
        BR      ONUM3A
ONUM2:  MOV      1,@ NFLAG       ;SELECT MODE
        BIC      177400,R0       ;TAKE CARE OF HIGH BYTE
        MOV      NUMBUF,R1       ;OUTPUT BUFFER LOCATION
        MOVB     SPACE,(R1)+     ;SPACE ON SCREEN
ONUM3A: CLR     R3               ;WORKING REGISTER
        CLR     R4               ;WORKING REGISTER
        MOV     R0,R2            ;NUMBER --> R2
```

```
; PERFORM OCTAL TO DECIMAL CONVERSION.
S7L23:  SUB     144,R2
        BMI     S7P24
        INC     R3
        MOV     R2,R0
        BR      S7L23
S7P24:  MOV     R0,R2
S7L24:  SUB     12,R2
        BMI     S7P25
        INC     R4
        MOV     R2,R0
        BR      S7L24
; CONVERT EACH DIGIT TO AN ASCII CHARACTER.
S7P25:  TST     @ NFLAG
        BEQ     ON2
ON4:    ADD     260,R3
        MOVB    R3,(R1)+      ;LOAD INTO OUTPUT BUFFER
ON3:    ADD     260,R4
        MOVB    R4,(R1)+      ;LOAD INTO OUTPUT BUFFER
        ADD     260,R0
        MOVB    R0,(R1)+      ;LOAD INTO OUTPUT BUFFER
        TST     @ NFLAG
        BEQ     ON5
        MOVB    SPACE,(R1)+       ;SPACE
        MOVB    SPACE,(R1)+       ;SPACE
ON5:    CLRB    (R1)              ;TRAILING ZERO
        MOV     NUMBUF,R0         ;LOCATION OF BUFFER
        JSR     PC,OUTPUT         ;NUMBER TO TERMINAL
        RTS     PC                ;RETURN
ON2:    TST     R3
        BEQ     ON3
        BR      ON4
; SECTION 8-4. OUTPUT MESSAGE TO CRT TERMINAL
OUTPUT: TSTB    @ TTXCSR                 ;OUTPUT MESSAGE
        BPL     OUTPUT
        MOVB    (R0)+,@ TTXBUF
        TSTB    (R0)
        BNE     OUTPUT
        RTS     PC
; SECTION 9. SUBROUTINE TO PERFORM SEARCH FOR BACKWALL
; IN ARRAY. THE SUBROUTINE PASSES THE ROW NUMBERS OF
; THE TOP AND BOTTOM OF THE BACKWALL TO THE CALLING
; ROUTINE THROUGH LOCATIONS ROW1 AND ROW2.  A FLAG
; IS SET IF A SUITABLE IMAGE OF THE BACKWALL IS NOT
; FOUND.
SEARCH:
        CLR     @ FLAG1
        MOV     70000,R0   ;STARTING POINT
        MOV     377,R4     ;NUMBER OF ROWS
        MOVB    @ NOISE,R2 ;R2 = NOISE
        CLR     R3         ;NUMBER OF COLUMNS > NOISE

S5L1:   MOV     6,R5       ;NUMBER OF SAMPLE COLUMNS
```

```
        CMP     R3,R5       ;ALL COLUMNS > NOISE?
        BEQ     FRNTW1      ;IF YES, JUMP TO FRONT WALL
FOUND
        MOV     R0,R1       ;RESET COLUMN POINTER
        CLR     R3      ;RESET NUMBER OF COLUMNS > NOISE
S5L2:   CMPB    R2,(R1)     ;COMPARE TO NOISE LEVEL
        BPL     S5P1        ;SKIP IF PIXEL <= NOISE
        INC     R3          ;PIXEL > NOISE
S5P1:   ADD      10000,R1   ;MOVE TO NEW COLUMN
        SOB     R5,S5L2  ;REPEAT FOR ALL SAMPLE COLUMNS
        INC     R0          ;MOVE TO NEXT ROW
        SOB     R4,S5L1     ;TEST FOR LAST ROW
        JMP     S5ERR1      ;BRANCH TO ERROR1
FRNTW1: MOV      6,R5       ;NUMBER OF SAMPLE POINTS
        CMPB    R3, 2       ;2 COLUMNS > NOISE?
        BMI     FRNTW2      ;IF NOT, BRANCH TO FRNTW2
        MOV     R0,R1       ;RESET COLUMN POINTER
        CLR     R3          ;RESET PIXEL COUNT
S5L3:   CMPB    R2,(R1)     ;COMPARE TO NOISE LEVEL
        BPL     S5P3        ;SKIP IF PIXEL <= NOISE
        INC     R3          ;COUNT PIXELS > NOISE
S5P3:   ADD      10000,R1   ;MOVE TO NEW COLUMN
        SOB     R5,S5L3    ;REPEAT FOR ALL SAMPLE POINTS

        INC     R0          ;MOVE TO NEXT ROW
        SOB     R4,FRNTW1   ;TEST FOR LAST ROW
        JMP     S5ERR1      ;BRANCH TO ERROR1
FRNTW2: MOV     R1,@ ROW3   ;STORE BOTTOM OF FRONTWALL
        CLRB    @ ROW3+1
S5L90:  MOV      6,R5       ;NUMBER OF SAMPLE POINTS
        CMPB    R3,R5       ;ALL PIXELS > NOISE
        BEQ     BACKW1      ;IF YES, BRANCH TO BACKW1
        MOV     R0,R1       ;RESET COLUMN POINTER
        CLR     R3          ;RESET PIXEL COUNTER
S5L4:   CMPB    R2,(R1)     ;COMPARE TO NOISE LEVEL
        BPL     S5P4        ;SKIP IF PIXEL <= NOISE
        INC     R3          ;COUNT PIXELS > NOISE
S5P4:   ADD      10000,R1   ;MOVE TO NEW COLUMN
        SOB     R5,S5L4    ;REPEAT FOR ALL SAMPLE POINTS
        INC     R0          ;MOVE TO NEXT ROW
        SOB     R4,S5L90    ;TEST FOR LAST ROW
        JMP     S5ERR1      ;BRANCH TO ERROR1
BACKW1: DEC     R1
        MOV     R1,@ ROW1   ;STORE TOP OF BACKWALL
        CLRB    @ ROW1+1
S5L41:  MOV      6,R5       ;NUMBER OF SAMPLE POINTS
        CMPB    R3, 2       ;2 SAMPLES >NOISE?
        BMI     BACKW2      ;IF NOT, BRANCH TO BACKW2
        MOV     R0,R1       ;RESET COLUMN POINTER IN NEW
ROW
        CLR     R3          ;CLEAR SAMPLE COUNTER
S5L5:   CMPB    R2,(R1)     ;COMPARE TO NOISE LEVEL
        BPL     S5P5        ;SKIP IF PIXEL <= NOISE
```

```
         INC      R3            ;COUNT PIXELS > NOISE
S5P5:    ADD       10000,R1     ;MOVE TO NEW COLUMN
         SOB      R5,S5L5     ;REPEAT FOR ALL SAMPLE POINTS
         INC      RO            ;MOVE TO NEXT ROW
         SOB      R4,S5L41      ;TEST FOR LAST ROW
         JMP      S5ERR1      ;ON LAST ROW, BRANCH TO ERROR1
BACKW2:  DEC      R1
         MOV      R1,@ ROW2     ;STORE BOTTOM OF BACKWALL
         CLRB     @ ROW2+1
         RTS      PC
; ERROR -- BACKWALL NOT FOUND
S5ERR1:
         MOV       1,@ FLAG1
         MOV       0,@ FLAG2
         MOV       WIPE,RO             ;CLEAR SCREEN
         JSR      PC,OUTPUT
         MOV       EMESS1,RO   ;LOCATION OF ERROR MESSAGE
         JSR      PC,OUTPUT      ;PRINT ERROR MESSAGE
         RTS      PC             ;RETURN
; SECTION 11. PUTS A FRAMESTORE ON D-BUS
;      THIS SUBROUTINE ALLOWS THE USER TO PLACE ONE OF
; THE FRAMESTORES ON DISPLAY.
DFRAME:
         MOV       WIPE,RO       ;CLEAR SCREEN
         JSR      PC,OUTPUT
         MOV       DMESS1,RO     ;LOCATION OF MESSAGE
         JSR      PC,OUTPUT
         MOVB     @ DBUS,RO      ;WHO'S ON D-BUS
         JSR      PC,ONUM2     ;TELL USER WHAT BUS HE'S ON
         MOV       DMESS2,RO
         JSR      PC,OUTPUT
         MOVB     @ DBUS,R3
         JSR      PC,INNUM        ;RETRIEVE NUMBER
         MOVB     R3,@ DBUS       ;STORE CHANGE
         TST      @ DBUS
         BEQ      S11P1
         CLR      @ QBUS
         BR       S11P2
S11P1:   MOV       1,@ QBUS
S11P2:   MOV      @ QBUS,@ FRAMEB
         JSR      PC,DISPLY       ;SWITCH FRAME ON SCREEN
         RTS      PC
; SECTION 12. SUM OVER BACKWALL IN COLUMN
;      SUBROUTINE SUMMER IS USED TO SUM VALUES OF
; THE BACKWALL IN A COLUMN.  THIS GIVES US A TOTAL
; ENERGY REPRESENTATION OF THE BACKWALL.  THE RESULT
; IS STORED IN A VECTOR IN MEMORY WHICH CAN THEN BE
; ACCESSED BY THE SMOOTHING AND BACKWALL DISPLAY
; SUBROUTINES.
; REGISTER USES:
;    RO=PIXEL BUFFER
;    R1=CUMULATIVE ROW SUM
;    R2=CURRENT COLUMN
```

```
;    R3=BACKWALL START ADDRESS
;    R4=COUNTER (WIDTH)
;    R5=PIXEL POINTER
SUMMER:
        CLR     R2              ;FIRST ARRAY ELEMENT
        MOV      60000,R3       ;FIRST COLUMN
        ADD     @ ROW1,R3       ;STARTING POINT
        MOV     @ ROW2,R4       ;COMPUTE WIDTH OF BACKWALL
        SUB     @ ROW1,R4
        INC     R4
        MOV     R4,@ WIDTH      ;STORE WIDTH OF BACKWALL
; THE OUTER LOOP COMPUTES THE SUM FOR EACH OF THE
; COLUMNS IN THE FRAME.
S12L1:
        CLR     R1            ;SUM=0
        MOV     @ WIDTH,R4 ;LOAD COUNTER FOR INNER LOOP
        MOV     R3,R5         ;SET UP PIXEL POINTER
; THE INNER LOOP ACTUALLY PERFORMS THE SUMMING
; OPERATION FOR A PARTICULAR COLUMN.
S12L2:
        MOVB    (R5)+,R0      ;PIXEL TO BUFFER
        ADD     R0,R1         ;SUM OVER BACKWALL
        SOB     R4,S12L2      ;COUNT UNTIL DONE
; HERE WE CONTROL THE OUTER LOOP COUNT AND STORE THE
; SUM OBTAINED FROM THE INNER LOOP.
        MOV     R1,BACKWL(R2) ;MOVE SUM INTO VECTOR
        ADD      400,R3         ;INCREMENT ROW POINTER
        ADD      2,R2         ;INCREMENT VECTOR SUBSCRIPT
        CMP      354,R2         ;TEST FOR END OF WALL
        BNE     S12L1           ;LOOP UNTIL DONE
; BACKWL THRU BACKWL+352 CONTAIN THE SUM OVER WALL AT
; EACH COLUMN.
S12P2:
        RTS     PC              ;RETURN
; SECTION 14. FLAW DETECTION PROGRAM
;      THIS SUBROUTINE DOES THE ACTUAL DETECTION.  THE
; ROUTINE USES SUBROUTINE SEARCH TO FIND THE BACKWALL.
; IT THEN EXAMINES THE WALL IMAGE FOR SHADOWS FROM THE
; FLAWS.
; IF SUCH SHADOWS ARE FOUND AND CFLAG=1 THE PROGRAM
; ATTEMPTS TO LOCATE THE ACTUAL IMAGE OF THE FLAW AND
; HIGHLIGHT IT WITH A BOX FOR THE USER TO SEE.
; IF CFLAG=0 THEN THE FLAW PICTURE LOCATION IS LOGGED
FLAWDP:
        JSR     PC,SEARCH     ;LOCATE BACKWALL
        TSTB    @ FLAG1       ;LOCATION OK?
        BEQ     S14P1         ;IF OK, CONTINUE
        TST     @ CFLAG       ;IF CFLAG =0 THEN A FLAW
        BNE     FRET          ;  MAYBE PRESENT AND IS
LOGGED
        JMP     END           ;   AS A PRECAUTION
FRET:   RTS     PC            ;OTHERWISE, RETURN
S14P1:
```

```
        JSR     PC,SUMMER     ;SUM OVER INNER SURFACE
        JSR     PC,SMOOTH     ;CREATE SMOOTHED VECTOR
;       THIS SUBSECTION COMPUTES THE AVERAGE AND THE
; MINIMUM FOR THE BACKWALL.  A COMPARISON OF THESE
; TWO NUMBERS IS THEN MADE.  IF NO POINT IN THE WALL
; FALLS BELOW .4 OF THE AVERAGE FOR THE WALL; IT IS
; SAFE TO ASSUME THAT NO FLAW IS PRESENT.  WE USE
; THIS CRITERION BECAUSE THE SHADOW THRESHOLD WILL
; BE SET AS APPROXIMATLY .4 OF THE OVERALL AVERAGE
; AND WE DON'T WANT TO WASTE TIME WITH A MORE DETAILED
; SEARCH IF NO VALUE WILL SATISFY THE CRITERION FOR A
; SHADOW.
; REGISTER USES IN THIS SUBSECTION:
;    R0=LOCAL AVERAGE OF ARRAY
;    R1=MINIMUM FROM ARRAY
;    R2=INDEX TO ARRAY
;    R3=AVERAGE OF ARRAY
;    R5=COUNTER
; THE BACKWALL IS DIVIDED INTO 13 SECTIONS OF 8 VALUES
; EACH WHEN COMPUTING THE AVERAGE.  THIS IS DONE SO
; THAT OVERFLOW OF REGISTERS DOES NOT BECOME A PROBLEM.
S14P2:
        MOV      SMTHBW,R2     ;INITIALIZE INDEX
        MOV      15,R5         ;INITIALIZE COUNTER
        CLR     R3             ;INITIALIZE SUM
        MOV     (R2),R1        ;INITIALIZE MINIMUM
S14L1:
        MOV      10,R4         ;SET UP INNER LOOP
        CLR     R0             ;CLEAR SUM
; THIS LOOP FINDS THE MINIMUM AND AVERAGE FOR A GROUP
; OF 8 VALUES.
S14L2:
S14P3:  CMP     R1,(R2)       ;LOOK FOR MINIMUM
        BMI     S14P4         ;STORE NEW MIN. IF NESS.
        MOV     (R2),R1
S14P4:
        ADD     (R2)+,R0      ;SUM ACROSS VALUES
        SOB     R4,S14L2      ;LOOP UNTIL DONE
        ASR     R0            ;COMPUTE LOCAL AVERAGE
        ASR     R0
        ASR     R0
        ADD     R0,R3         ;ADD TO OVERALL SUM
        SOB     R5,S14L1      ;LOOP FOR 13 SECTIONS
; NOW MAKE THE COMPARISON TO SEE IF ANY MINIMUM VALUES
; FALL BELOW .4 OF THE OVERALL AVERAGE.
        MOV     R3,@ AVE          ;STORE 13 TIMES AVERAGE
        MOV     R1,@ MIN          ;STORE MINIMUM VALUE
        ASL     R1                ;MULTIPLY MINIMUM BY 32
        ASL     R1
        ASL     R1
        ASL     R1
        ASL     R1
        CMP     R1,R3             ;COMPARE AS TEST
```

```
        BMI     TESTFL           ;CONTINUE IF R1 < R3
;
; NO FLAW FOUND IN CURRENT PICTURE.
NOTHIN: TST     @ CFLAG          ;FULL TEST?
        BEQ     NOTH1            ;NO - DON'T DISPLAY A
MESSAGE
        MOV      FMESS1,R0      ;PRINT 'NO FLAWS
DETECTED'
        JSR     PC,OUTPUT
NOTH1:  RTS     PC
; IF THE FIRST TEST INDICATES THAT A SHADOW MAY BE
; FOUND, WE COMPUTE THE THRESHOLD AS A FUNCTION OF
; THE LOCAL AVERAGE.  THIS FUNCTION IS .4 TIMES THE
; AVERAGE PLUS A SHADOW NOISE FACTOR.  THIS VALUE
; FOR THE THRESHOLD IS WHY WE RAN THE FIRST TEST TO
; SEE IF ANY POINT WOULD SATISFY THIS CRITERION.
TESTFL:
        ASR     R3              ;DIVIDE BY 32
        ASR     R3
        ASR     R3
        ASR     R3
        ASR     R3
        ADD     @ SHADOW,R3 ;ADD A SHADOW NOISE FACTOR
        MOV      SMTHBW,R0  ;R0 WILL POINT TO SMOOTHED
; ARRAY THAT WAS FORMED BY SMOOTH ROUTINE.
        MOV      150,R5      ;NUMBER OF POINTS IN ARRAY
        MOV      BORDRS,R1  ;BORDERS OF SHADOWS GO HERE
        CLR     R2              ;CLEAR COUNT OF BORDERS
; TEST FOR HIGH TO LOW THRESHOLD TRANSITION
S14L10:
        CMP     (R0)+,R3    ;COMPARE TO THRESHOLD
        BPL     S14P10      ;LOOP IF HIGH
        MOV     R0,(R1)     ;LOG LOCATION OF TRANSITION
        SUB      2,(R1)+
        INC     R2          ;INCREMENT COUNT
        JMP     S14P11      ;NOW TEST FOR LOW TO HIGH
; TEST FOR LOW TO HIGH THRESHOLD TRANSITION
S14L11:
        CMP     (R0)+,R3    ;COMPARE TO THRESHOLD
        BMI     S14P11      ;SKIP IF LOW
        MOV     R0,(R1)     ;LOG LOCATION OF TRANSITION
        SUB      2,(R1)+
        INC     R2          ;INCREMENT COUNT
        JMP     S14P10      ;REJOIN HIGH LOOP
S14P11: SOB     R5,S14L11 ;CONTINUE LOW LOOP UNTIL DONE
; IT MAY BE THAT THE LAST SHADOW EXTENDS OFF THE SCREEN
; IN THIS CASE WE ADD A FINAL BORDER TO EVEN THINGS UP.
        MOV     R0,(R1)    ;ADD FINAL BORDER IF NESS.
        SUB      2,(R1)+
        INC     R2         ;ADD LAST BORDER TO COUNT
        JMP     S14P20     ;MOVE ON
S14P10: SOB     R5,S14L10 ;CONTINUE HIGH LOOP UNTIL END
; AFTER ALL 150 ELEMENTS OF THE SMOOTHED ARRAY HAVE
```

```
; BEEN TESTED, AN ARRAY OF LOCATIONS WHERE BORDERS
; OCCURRED HAS BEEN CREATED. THERE IS AN EVEN NUMBER
; OF BORDERS.  IF THE COUNT OF BORDERS = 0, THEN
; THERE IS NO FLAW AND WE RETURN TO THE COMMAND
; ROUTINE.
S14P20:
        TST     R2
        BEQ     NOTHIN
;
; FLAW(S) HAVE BEEN FOUND CHECK  IF MORE PROCESSING
WANTED.
; CFLAG=0 NO-LOG  CFLAG=1 YES - DRAW BOXES ECT.
;
        TST     @ CFLAG
        BNE     ARRAY
        JMP     END             ;NO MORE POCESSING
;
; THE BORDERS ARRAY CONSISTS OF LOCATIONS IN THE
; SMOOTHED ARRAY VECTOR WHICH WE GENERATED FROM
; THE DATA IN THE FRAME.  THIS SUBSECTION TRANSLATES
; THESE LOCATIONS INTO LOCATIONS IN THE FRAMESTORE.
ARRAY:
        MOV     R2,R5           ;INIT. COUNT
        MOV      BORDRS,R0      ;LOC. OF BORDERS ARRAY
S14L30:
        SUB      SMTHBW,(R0) ;SUBTRACT OFFSET OF ARRAY
        MOV      7,R4           ;SHIFT INDEX TO HIGH BYTE
S14L31:
        ASL     (R0)
        SOB     R4,S14L31
        ADD      60000,(R0) ;ADD OFFSET OF FRAMESTORE
        ADD     @ ROW1,(R0) ;ADD ROW   OF TOP OF WALL
        SUB      4,(R0)+     ;ADD A BREATHING SPACE
        SOB     R5,S14L30   ;DO FOR ALL BORDERS
; WE NOW SEARCH THE FRAMESTORE IN ORDER TO TRY TO DRAW
; BOXES AROUND THE FLAW.
; REGISTERS IN THIS SUBSECTION:
;    R0=POINTER TO BORDERS ARRAY
;    R1=POINTER TO FRAMESTORE
;    R2=HORIZONTAL SUM IN AREA
;    R3=HORIZONAL COUNTER
;    R4=VERTICAL COUNTER FOR SEARCH AREA
;    R5=NUMBER OF SEARCH AREAS
; FIRST WE COMPUTE THE VERTICAL RANGE THAT WILL BE
; SEARCHED FOR FLAWS.  IN DOING THIS WE WANT TO
; RESTRICT THE POINTER TO THE AREA BETWEEN THE TOP OF
; THE BACKWALL AND THE BOTTOM OF THE FRONTWALL.
BOXES:
        MOV      BORDRS,R0      ;BEGINNING OF ARRAY
        CLR     @ PIXEL         ;CLEAR PIXEL BUFFER
        MOV     R2,R5   ;COMPUTE NUMBER OF SEARCH AREAS
        ASR     R5
        MOV     @ ROW1,R4       ;COMPUTE VERTICAL RANGE
```

```
        SUB     @ ROW3,R4
        SUB      10,R4          ;MARGIN
        MOV     R4,@ VRANGE     ;STORE VERTICAL RANGE
; NOW THE SEARCH BEGINS.  FOR EACH SEARCH AREA (REG5)
; WE LOOK FOR REGIONS OF HIGH REFLECTED INTENSITY.
; THESE REGIONS ARE HIGHLIGHTED BY A BOX.
; COMPUTE THE WIDTH OF THIS SEARCH AREA FROM THE
; LOCATIONS OF ITS BORDERS NEAR THE BACKWALL.
S14L40:
        MOV     (RO)+,@ RSIDE   ;LEFT SIDE OF AREA
        MOV     (RO),@ LSIDE    ;RIGHT SIDE OF AREA
        MOV     (RO)+,R3        ;COMPUTE HORIZONTAL AREA
        SUB     @ RSIDE,R3
        MOV      10,R1          ;DIVIDE
S14L99: ASR     R3
        SOB     R1,S14L99
        INC     R3
        MOV     R3,@ HRANGE     ;STORE HORIZONTAL RANGE
; LIMIT THE POINTER TO THE VERTICAL RANGE.  SET UP A
; FLAG WHICH WILL INDICATE IF SOMETHING WAS FOUND.

        MOV     @ VRANGE,R4     ;LOAD VERTICAL COUNTER
        CLR     @ FLAG4         ;CLEAR FLAG
; WE NOW SEARCH EACH ROW IN THE SEARCH AREA.  THE
; PIXELS IN THAT ROW ARE SUMMED AND COMPARED TO THE
; SIZE OF THE ROW.  IF ENOUGH INTENSITY IS FOUND, WE
; CONCLUDE THAT THIS IS PART OF A FLAW.  IF NOT, THE
; SEARCH MOVES TO THE NEXT ROW.
S14L41:
        MOV     @ RSIDE,R1      ;SET UP POINTER
        MOV     @ HRANGE,R3     ;INIT. HORIZ. COUNT
        CLR     R2              ;INIT. SUM
S14L42:
        MOVB    (R1),@ PIXEL    ;TAKE PIXEL
        ADD     @ PIXEL,R2      ;SUM OVER AREA
        ADD      400,R1         ;MOVE POINTER
        SOB     R3,S14L42       ;COVER ROW IN AREA
; IF A FLAW HAS BEEN FOUND WE'LL BRANCH AT THIS POINT
; TO A SECTION OF THE PROGRAM THAT LOOKS FOR THE TOP
; OF THE FLAW.  IF NONE HAS BEEN FOUND YET, WE CONTINUE
; WITH THE NEXT SUBSECTION; THIS LOOKS FOR THE BOTTOM
; OF THE FLAW.
        TST     @ FLAG4
        BNE     S14P43
; HERE WE COMPARE TO SEE IF A FLAW HAS BEEN FOUND. IF
; SO, WE BEGIN TO DRAW THE VERTICAL LINES WHICH MAKE
; UP TWO SIDES OF THE BOX AROUND THE FLAW.
S14P44:
        CMP     R2,@ NOISE2
        BMI     S14P45
        MOV     @ RSIDE,@ HOLD1 ;STORE BOTTOM OF FLAW
        INC     @ RSIDE          ;POSITION CURSOR
        INC     @ RSIDE
```

```
         INC     @ LSIDE
         INC     @ LSIDE
         DEC     @ RSIDE
         DEC     @ LSIDE
; DRAW VERTICAL LINES
         MOV     RO,-(SP)
         MOV     @ RSIDE,RO
         MOVB     77,(RO)
         MOV     @ LSIDE,RO
         MOVB     77,(RO)
         MOV     (SP)+,RO
; POSITION CURSOR
         DEC     @ RSIDE
         DEC     @ LSIDE
; DRAW VERTICAL LINES
         MOV     RO,-(SP)
         MOV     @ RSIDE,RO
         MOVB     77,(RO)
         MOV     @ LSIDE,RO
         MOVB     77,(RO)
         MOV     (SP)+,RO
; PLACE LOCATION OF BOTTOM OF BOX IN LOCATION HOLD1.
; SET THE FLAG WHICH INDICATES THAT WE ARE NOW LOOKING
; FOR THE TOP OF THE FLAW.
         ADD      2,@ HOLD1
         MOV     @ HRANGE,R3
         INC     @ FLAG4
S14P45:  DEC     @ RSIDE        ;MOVE TO NEXT ROW UP FRAME
         DEC     @ LSIDE
         DEC     R4             ;TEST VERTICAL LIMIT
         TST     R4
         BEQ     KLUGE1         ;IF AT TOP OF RANGE, EXIT
         JMP     S14L41         ;IF NOT, CONTINUE SEARCH
KLUGE1:  JMP     S14P60         ;JUMP TO EXIT SECTION
; IN THIS SUBSECTION WE ARE LOOKING FOR THE TOP OF A
; FLAW.  THE COMPARISON IS MADE FOR INTENSITY AGAIN.
; IF WE STILL HAVE ENOUGH INTENSITY TO INDICATE THE
; FLAW, WE EXTEND THE VERTICAL EDGES OF THE BOX.  WHEN
; THE TOP OF THE FLAW IS FOUND, THE TOP AND BOTTOM OF
; THE BOX ARE DRAWN AND WE MOVE TO THE NEXT SEARCH AREA
S14P43:
         CMP     R2,@ NOISE2    ;COMPARISON
         BPL     S14P55         ;IF TOP FOUND, JUMP
         MOV     @ RSIDE,R1     ;EXTEND VERTICAL LINES
         DEC     @ RSIDE
         DEC     @ LSIDE
; DRAW VERTICAL SECTIONS
         MOV     RO,-(SP)
         MOV     @ RSIDE,RO
         MOVB     77,(RO)
         MOV     @ LSIDE,RO
         MOVB     77,(RO)
         MOV     (SP)+,RO
```

```
; POSITION CURSORS
        DEC     @ RSIDE
        DEC     @ LSIDE
; DRAW VERTICAL SECTIONS
        MOV     RO,-(SP)
        MOV     @ RSIDE,RO
        MOVB     77,(RO)
        MOV     @ LSIDE,RO
        MOVB     77,(RO)
        MOV     (SP)+,RO
; HERE WE DRAW THE TOP AND BOTTOM OF THE BOX.
        SUB      2,R1          ;POSITION TOP OF BOX
        MOV     @ HRANGE,R3   ;LENGTH OF TOP LINE
S14L56:
        MOV      77,(R1)       ;DRAW LINE
        ADD      400,R1        ;MOVE TO NEXT COLUMN
        SOB     R3,S14L56     ;DRAW WHOLE LINE
        MOV     @ HOLD1,R1    ;POSITION BOTTOM OF BOX
        MOV     @ HRANGE,R3   ;LENGTH OF BOTTOM LINE
S14L96:
        MOV      77,(R1)       ;DRAW LINE
        ADD      400,R1        ;MOVE TO NEXT COLUMN
        SOB     R3,S14L96     ;DRAW WHOLE LINE
        CLR     @ FLAG4       ;CLEAR FLAG
        JMP     S14P60        ;GO BACK TO START
; FINISH VERTICAL SIDES OF BOX.
S14P55:
        MOV     RO,-(SP)
        MOV     @ RSIDE,RO
        MOVB     77,(RO)
        MOV     @ LSIDE,RO
        MOVB     77,(RO)
        MOV     (SP)+,RO
        DEC     @ RSIDE
        DEC     @ LSIDE
        DEC     R4
        TST     R4
        BEQ     S14P60
        JMP     S14L41
; TEST FOR END OF SEARCH AREAS. WHEN THE END IS FOUND,
; WE BRANCH TO THE CLEANUP SUBSECTION.  OTHERWISE, WE
; MOVE BACK TO A NEW SEARCH AREA
S14P60:
        DEC     R5         ;TEST FOR END
        TST     R5
        BEQ     END
        CLR     @ FLAG4    ;RESET FLAG
        JMP     S14L40     ;CONTINUE SEARCHES
; THIS SUBSECTION CLEANS UP,LOGS THE FLAW IF CFLAG=0
; OR CLAG=1 PRINTS A MESSAGE TO INDICATE THAT FLAW(S)
WERE
; FOUND
;
```

```
END:     TST     @ CFLAG
         BNE     END1
         MOV     @ NFLAWS,R0          ;LOG THE FLAW
         MOV      FLOG,R1             ; MAKE SURE THAT THE
         ADD     R0,R1                ; NUMBER OF FLAWS
WON'T
         CMP     R1, 37760            ; OVER WRITE OTHER
INFO
         BGE     MNYFLW               ;  TOO MANY FLAWS
         MOV     @ XLOC,FLOG(R0)      ;PUT IN XLOC
         INC     R0
         INC     R0
         MOV     @ CANGLE,FLOG(R0)    ;PUT IN ANGLE
         INC     R0
         INC     R0
         MOV     R0,@ NFLAWS        ;STORE OFFSET FOR NEXT
IN NFLAWS
;NOTE - NFLAWS HAS FOUR TIMES THE NUMBER OF FLAWS
         RTS     PC                 ;RETURN
END1:    MOV      FMESS2,R0       ;'FLAW(S) DETECTED'
         JSR     PC,OUTPUT
         RTS     PC
MNYFLW:  MOV      FMESS3,R0       ;'TOO MANY FLAWS
DETECTED'
         JSR     PC,OUTPUT
         RTS     PC
; SECTION 15. SMOOTHING SUBROUTINE
;      THIS SUBROUTINE TAKES THE VECTOR BACKWL AND
; DOES AN AVERAGING OPERATION TO SMOOTH THE CURVE.
; THE RESULTING VECTOR IS STORED IN SMTHBW.
; REGISTER USES:
;    R1 - TRAILING POINTER
;    R2 - LEADING POINTER
;    R3 - SUM
;    R4 - INDEX TO SMooTHed BackWall vector (SMTHBW)
;    R5 - COUNTER
;    R0 - POINTER
SMOOTH:
         CLR     R3                 ;CLEAR SUM
         MOV      10,R5             ;SET UP COUNT
         MOV      BACKWL,R1         ;INIT. TRAILING POINTER
         MOV      BACKWL+20,R2      ;INIT. LEADING POINTER
         MOV     R1,R0              ;INIT. POINTER
; COMPUTE SUM OF FIRST EIGHT PIXELS.
S15L1:
         ADD     (R0)+,R3           ;SUM OVER EIGHT PIXELS
         SOB     R5,S15L1
; HERE WE COMPUTE THE AVERAGE, AND STORE IT IN THE
; FIRST FOUR LOCATIONS OF THE OUTPUT ARRAY.
S15P1:
         MOV     R3,R0
         ASR     R0
         ASR     R0
```

```
        ASR     R0
        MOV     R0,@ SMTHBW
        MOV     R0,@ SMTHBW+2
        MOV     R0,@ SMTHBW+4
        MOV     R0,@ SMTHBW+6
; SET UP LOOP FOR REMAINING VALUES.  THE REST OF
; THE SUMS ARE COMPUTED IN AN OPTIMUM MANNER BY
; ONLY DEALING WITH TWO OF THE EIGHT VALUES IN
; THE SUM.  THE LEADING AND TRAILING POINTERS ARE
; USED TO CHANGE THE SUM.
S15P2:
        MOV      SMTHBW+10,R4
        MOV      156,R5
S15L2:
        ADD     (R2)+,R3        ;ADD NEW VALUE
        SUB     (R1)+,R3        ;SUBTRACT OLDEST VALUE
        MOV     R3,R0           ;COMPUTE AVERAGE
        ASR     R0
        ASR     R0
        ASR     R0
        MOV     R0,(R4)+        ;STORE IN OUTPUT ARRAY
        SOB     R5,S15L2        ;LOOP UNTIL END
; FILL LAST FOUR VALUES IN OUTPUT ARRAY WITH LAST VALUE
S15P3:
        MOV     R0,(R4)+
        MOV     R0,(R4)+
        MOV     R0,(R4)+
        MOV     R0,(R4)+
        RTS     PC              ;RETURN
; SECTION 16. INTERRUPT SERVICE
; SPACE IS ALLOCATED FOR FOUR INTERRUPT SERVICE
; SUBROUTINES.
IVECT1: JMP     COMMN1
IVECT2: JMP     COMMN1
IVECT3: JMP     COMMN1
IVECT4: JMP     COMMN1
; SECTION 17. UPLOAD FRAME STORE SUBROUTINE
; SUBROUTINE UPLOADS A SINGLE IMAGE FROM
; FRAMESTORE TO THE VAX/11 SYSTEM (7/12/82)
; THE LINECLOCK INTERRUPT SWITCH MUST BE OFF
UPLOAD:
        MOV      20776,SP       ;LOAD INTERRUPT VECTOR
        MOV      100,@ 176510

        MOV      400,R5         ;NUMBER OF ROWS
        MOV       157400,R0

LOOP:
 MOV     R0,R1          ;OUTPUT ON ROW
 JSR     PC,OTPT
 INC     R0
 SOB     R5,LOOP
;INFORM ME THAT UPLOAD IS DONE, THEN QUIT
```

```
          MOVB     330,@ 177566
 MOVB     32,@ 176516
 JMP      COMMN3              ;RETURN
;SUBROUTINE OTPT
OTPT:
 MOV      200,R4              ;NUMBER OF COLUMNS
LOOP1:
 CMP      100,R4
 BNE      DOIT
 MOV      15,R2               ;LOAD <CR>
 MOV      100,@ 176514        ;ENABLE INTERRUPT
 WAIT                         ;WAIT FOR INTERRUPT
DOIT:
 MOVB     (R1),R2             ;MOVE PIXEL TO BUFFER
 MOV      R2,R3
 BIC      177770,R3           ;LOW ORDER DIGIT IN REG3
 BIS      60,R3               ;ASCII
 BIC      177707,R2           ;HIGH ORDER DIGIT IN REG2
 CLC
 ROR      R2
 ROR      R2
 ROR      R2
 BIS      60,R2               ;ASCII
 MOV      100,@ 176514        ;ENABLE INTERRUPT
 WAIT
 MOV      R3,R2
 MOV      100,@ 176514        ;ENABLE INTERRUPT
 WAIT                         ;WAIT FOR INTERRUPT
;UPDATE POINTER, COUNT, AND LOOP BACK
 SUB      400,R1
 SOB      R4,LOOP1
;WHEN ROW IS DONE, OUTPUT <CR>, UPDATE POINTER AND
COUNT, THEN LOOP BACK
 MOV      15,R2               ;LOAD <CR>
 MOV      100,@ 176514        ;ENABLE INTERRUPT
 WAIT                         ;WAIT FOR INTERRUPT

 RTS      PC
;INTERRUPT SERVICE SUBROUTINE TXINT
TXINT:
 MOVB     R2,@ 176516         ;OUTPUT CHARACTER
 BIC      100,@ 176514        ;DISABLE INTERRUPT
 RTI
RXINT:
 MOVB     @ 176512,@ 21000            ;READ CHARACTER
 BIC      177600,@ 21000              ;MASK
 CMP      @ 21000, 23                 ;S ?
 BNE      RETI
L1:
 TSTB     @ 176510
 BPL      L1
 MOVB     @ 176512,@ 21000            ;READ CHARACTER
 BIC      177600,@ 21000              ;MASK
```

```
 CMP     @ 21000, 21             ;Q?
 BNE     L1
RETI:
 RTI
;
; THIS SECTION HAS MOST OF THE ROUTINES WHICH INVOLVE
; POSITIONING THE ARRAY AND DISPLAYING THE FLAW LOG.
; THIS COMPOSES MOST OF THE CODE WRITTEN BY RONALD
BURGIN.
;
; LOCATE -THIS SECTION LOCATES AND DISPLAYS FLAWS
;        GIVEN THE FLAW LOG NUMBER.  IT ALLOWS
;        THE USER TO ADJUST THE POSITION THAT
;        WILL BE PROCESSED. PICT FLAGS WHEN TO TAKE
;        A PICTURE ( CAN TAKE WHEN PICT=0)
;
LOCATE: ADD      31,@ MAXX        ;ADD TWO INCHES TO
MAX LENGTH
        TST     @ KFLAG           ;WAS <S> PRESSED
WHILE IN JIGGLE?
        BEQ     LOCAT1            ;NO, CONTINUE
        MOV     (SP)+,RO          ;YES POP RETURN
ADDRESS
        CLR     @ KFLAG           ;  AND RESET KEYBOARD
FLAG.
LOCAT1: MOV      1,@ PICT         ;DISABLE PICTURE
        MOV      LM1,RO          ;'ENTER FLAW  '
        JSR     PC,OUTPUT
        MOV      177777,R3          ;THIS SETS UP TEST
FOR
        JSR     PC,INNUM           ;GET THE RESPONSE
        CMP     R3, 177777          ;A RETURN WITH NO
NUMBER
        BEQ     LOCD               ;PERSON PRESSED
<RETURN>
        DEC     R3                 ;FLAW  1 IS AT
OFFSET O IN LOG
        ASL     R3                 ;MULTIPLY RESPONSE
BY 4
        ASL     R3                 ;TO CALCULATE
DISPLACEMENT IN FLAW LOG
        TST     @ NFLAWS           ;CHECK TO SEE IF
THERE ARE ANY FLAWS
        BEQ     LOCA9              ;NO THERE ISN'T
        CMP     R3,@ NFLAWS        ;LEGAL ENTRY?
        BLE     GPOS               ;LEGAL POSITION
ENTERED
LOCA9:  JMP     ILPOS              ;BAD FLAW NUMBER
ENTERED
GPOS:   MOV      LM3,RO            ;PRINT INSTRUCTIONS
        JSR     PC,OUTPUT
        JSR     PC,JIGGLE          ;RESET CURRENT ANGLE
        MOV     FLOG(R3),@ TPOSX   ;GET DESIRED
```

```
POSITION OFF LOG
        MOV      1,@ MFLAG          ;SET MOTOR SENSITIVE
        CMP     @ TPOSX,@ DISP      ;CHECK TO SEE IF AT
FAR RIGHT END
        BNE     LOCNT               ;NO -WE EXPECT MOTOR
TO MOVE
        CLR     @ MFLAG             ;NOT MOTOR SENSITIVE
EXPECTING TROUBLE
LOCNT:  INC     R3                  ;CALCULATE LOCATION
OF THE ANGLE IN
        INC     R3                  ; THE FLAW LOG.
        MOV     FLOG(R3),@ TANGLE   ; GET THE ANGLE
LOCLP:  MOV     @ TPOSX,R2
        CMP     R2,@ XLOC           ;DECIDE WHICH WAY TO
GO
        BEQ     LOCA2               ;ALREADY AT THE X
POSITION
        BLO     MOVRT               ;HAVE TO MOVE RIGHT
        MOV      1,@ DIR            ;SET UP TO MOVE
ARRAY LEFT
        SUB     @ XLOC,R2           ;CALCULATE THE
DIFFERENCE IN COUNTS
        BR      LOCMOV
MOVRT:  MOV      0,@ DIR            ;SET UF FOR MOVE TO
THE RIGHT
        MOV     @ XLOC,R2
        SUB     @ TPOSX,R2        ;CALCULATE THE
DIFFERENCE IN COUNTS
LOCMOV: MOV     R2,R1
        JSR     PC,MOTOR          ;SEND THE COUNT
        BR      LOCA2
;
LOCD:   SUB      31,@ MAXX        ;SUBTRACT OFF 2 INCHES
        JMP     COMMN2            ;LOCATE DONE- RETURN
TO COMMAND MODE
;
; NOW WAIT UNTIL ANGLE DESIRED PASSES BY
;    AND WHILE WAITING CHECK FOR KEY PRESSES
; PICT CONTROLS WHEN THE PROGRAM CAN TAKE A PICTURE
;
LOCA2:  TST     @ KFLAG          ;WAS KEY PRESSED WHILE
IN JIGGLE?
        BEQ     LOCA2B
        JMP     J3               ;IF SO RETURN THERE
LOCA2B: INC     @ MFLAG          ;SET  MOTOR SENSITIVE
        TST     @ PICT           ;CAN TRY TO TAKE
PICTURE ?
        BEQ     LOCA2C             ; YES
        CMP     @ CANGLE,@ TANGLE  ;SEE IF CURR ANGLE
IS LESS TARGET ANGLE
        BGT     LOCA2A             ;NO CHECK KEYBOARD
        CLR     @ PICT          ;PICT CLEAR CAN TAKE
PICT WHEN POSSIBLE
```

```
LOCA2C: CMP     @ CANGLE,@ TANGLE  ;ANGLE PASSED?
        BLT     LOCA2A             ; NO CHECK KEY BOARD
        INC     @ PICT             ;PICT =1 PICTURE
TAKEN
        JMP     LOCA3              ;GO TAKE PICTURE
LOCA2A: TSTB    @ TRDCSR           ;CHECK KEYBOARD
        BPL     LOCA2              ;NO KEY PRESSED
LOCA21: MOVB    @ TRDBUF,R1        ;READ THE KEY
        BIC      177600,R1
        CMP      113,R1            ;UP ARROW KEY(K)
PRESSED?
        BEQ     LOCUP              ; YES ADD 1/2 DANGLE
        CMP      112,R1            ;DOWN ARROW KEY(J)
PRESSED?
        BEQ     LOCDW              ; YES SUB 1/2 DANGLE
        CMP      114,R1            ;RIGHT ARROW KEY(L)
PRESSED?
        BEQ     LOCRT              ; YES MOVE ARRAY .24
INCHES RIGHT
        CMP      110,R1            ;LEFT ARROW KEY(H)
PRESSED?
        BEQ     LOCLFT             ; YES MOVE ARRAY .24
INCHES LEFT
        CMP      123,R1            ;"S" PRESSED
        BEQ     LOCAT1             ;YES GO SEE WHAT USER
WANTS
        CMP      120,R1            ; P PRESSED?
        BEQ     DISPL              ; PRINT CURRENT
TARGET POSITION
        BR      LOCA2              ;IGNORE RESPONSE
LOCUP:  MOV     @ DANGLE,R1        ;CHANGE TARGET ANGLE
        ASR     R1                 ; BY PLUS ONE HALF
DANGLE
        ADD     R1,@ TANGLE
        CMP     @ TANGLE, 23040.   ;MAKE SURE ANGLE IS
VALID
        BMI     LOCA2
        SUB      23040.,@ TANGLE
        BR      LOCA2
LOCDW:  MOV     @ DANGLE,R1        ;CHANGE TARGET ANGLE
        ASR     R1                 ; BY MINUS ONE HALF
DANGLE
        SUB     R1,@ TANGLE
        BPL     LOCA2              ;MAKE SURE ANGLE IS
VALID
        ADD      23040.,@ TANGLE
        BR      LOCA2
LOCRT:  MOV      3,R1              ;MOVE MOTOR .24 INCH
RIGHT
        CLR     @ DIR
        JSR     PC,MOTOR
        BR      LOCA2
LOCLFT: MOV      3,R1              ;MOVE MOTOR .24 INCH
```

```
LEFT
        MOV     1,@ DIR
        JSR     PC,MOTOR
        BR      LOCA2
DISPL:  MOV     POSPRT,RO        ;PRINT CURRENT TARGET
POSITION
        JSR     PC,OUTPUT
        MOV     @ XLOC,R1
        MOV     @ TANGLE,R2
        JSR     PC,DPOSA
        JMP     LOCA2
ILPOS:  MOV     LM2,RO            ;'ILLEGAL FLAW
NUMBER'
        JSR     PC,OUTPUT
        JMP     LOCAT1
;
;   TAKE THE PICTURE
;
LOCA3:  INC     @ PICT
        MOV     @ QBUS,@ FRAMEA    ;SET UP FRAMES
        MOV     @ DBUS,@ FRAMEB
        JSR     PC,SAMPLE          ;TAKE SAMPLE
        MOV     1,@ CFLAG          ;SET FURTHER TESTING
FLAG
        JSR     PC,FLAWDP          ;FIND FLAWS
        JSR     PC,CLEAN           ;CLEAN UP PICTURE
BELOW BACKWALL
        MOV     @ QBUS,@ FRAMEA    ;CLEAR THE
        MOV     @ QBUS,@ FRAMEB    ; OTHER
        JSR     PC,FSCLRP          ; FRAME FOR NEXT
PICTURE
        TST     @ QBUS             ;SWAP WHICH FRAME
WILL HAVE
        BEQ     LOCA4              ;NEXT PICTURE
        CLR     @ QBUS
        INC     @ DBUS
        BR      LOCA5              ;GO BACK AND WAIT
FOR NEXT PASS
LOCA4:  CLR     @ DBUS
        INC     @ QBUS
LOCA5:  MOV     1,@ KFLAG          ;SET KEYBOARD FLAG
        JSR     PC,JIGGLE
        CLR     @ KFLAG            ;CLR KEYBOARD FLAG
        JMP     LOCA2
;
;SCAN - THIS ROUTINE CONTROLS THE SCANNING OF THE
BILLET.
;       BILLET POSITION IS HANDLED BY THE LINE CLOCK
;       INTERRUPT ROUTINE.  CFLAG IS CLEARED SO THAT
;       THE FLAW FINDING ROUTINE WILL LOG THE FLAWS.
;       A FLAW IN THE FLAW LOG IS TWO WORDS WIDE.
;       THE FIRST WORD HAS THE NUMBER OF COUNTS FROM
;       THE RIGHT OF THE FLAW.  THE SECOND WORD HAS THE
```

```
;       ANGLE THAT THE FLAW WAS FOUND AT.  NOTE THE
;       ANGLE IS REPRESENTED AS THE ANGLE * 64.  THIS
WAS
;       DONE SINCE INCREASED ACCURACY WAS DESIRED AND
;       FLOATING POINT NUMBERS AREN'T SUPPORTED.
;       NUMTIK HAS THE NUMBER OF LINE CLOCK INTERRUPTS
;       THAT WILL OCCUR IN ONE ROTATION.  THIS IS USED
;       TO DECIDE WHEN TO MOVE THE ARRAY.
;
SCAN:   MOV     1,@ MFLAG             ;MOTOR SENSITIVE
        CLR     @ NFLAWS
        CLR     @ CFLAG               ;RESET FURTHER
TESTING FLAG
AOLOOP: JSR     PC,JIGGLE             ;RESET ANGLE TO 0
        CLR     @ NTICKS
AILOOP: MOV     @ QBUS,@ FRAMEA       ;SET UP FRAMES
        MOV     @ DBUS,@ FRAMEB
        JSR     PC,SAMPLE             ;TAKE A PICTURE
        JSR     PC,FLAWDP             ;CHECK FOR FLAWS
        JSR     PC,CLEAN              ;CLEAN UP PICTURE
BELOW BACKWALL
        TST     @ QBUS                ;SWAP FRAMES
        BEQ     SCAN99
        CLR     @ QBUS
        INC     @ DBUS
        BR      SCAN98
SCAN99: CLR     @ DBUS
        INC     @ QBUS
SCAN98: TSTB    @ TRDCSR              ;KEY PRESSED?
        BMI     SCAND
        CMP     @ NTICKS,@ NUMTIK     ;COMPLETED A
ROTATION ?
        BLT     AILOOP                ;NO
        MOV     @ XLOC,R1             ;CHECK TO SEE IF
END REACHED
        ADD     62,R1
        CMP     R1,@ MAXX             ;REACHED LEFT SIDE
        BGT     SCAND                 ;SCAN COMPLETE
        MOV     62,R1                 ;MOVE ARRAY FOUR
INCHES
        MOV     1,@ DIR
        JSR     PC,MOTOR
        CLR     @ NTICKS
SCN100: CMP     454,@ NTICKS         ;KILL 5 SECONDS TO
ALLOW ARRAY TO
        BGT     SCN100               ;STOP MOVING.
        BR      AOLOOP
;
;  DISPLAY THE NUMBER OF FLAWS FOUND.
;    NFLAWS WILL HAVE 4 TIMES THE NUMBER FOUND.
;
SCAND:  MOV     @ TRDBUF,R0          ;READ DUMMY KEY FOR
INCOMPLETE SCAN
```

```
        MOV     MSCAN1,R0           ;"SCAN COMPLETE"
        JSR     PC,OUTPUT
        MOV     @ NFLAWS,R0         ;NFLAWS HAS 4 TIMES
THE NUMBER OF FLAWS
        ASR     R0                  ;CALCULATE THE
ACTUAL NUMBER OF FLAWS
        ASR     R0                  ; BY DIVIDING BY 4
        JSR     PC,ONUM3            ;PRINT THE NUMBER
OF FLAWS
        MOV     MSCAN2,R0           ;" FLAWS FOUND"
        JSR     PC,OUTPUT
SCAND1: TSTB    @ TRDCSR             ;WAIT FOR A KEY TO
BE PRESSED
        BPL     SCAND1
        JMP     COMMN2
;
;DISPLAY - THIS ROUTINE IS USED TO DISPLAY A FLAWS
POSITION.
;          THE ROUTINE USES .08 INCHES PER COUNT. THE
ACTUAL
;          COUNT IS .079 INCHES.
;R1 HAS X POS. R2 HAS ANGLE
;
DPOSA:  MOV     R2,@ SAVE2      ;SAVES THE ANGLE
        SUB     @ DISP,R1       ;SUBTRACT OFF THE
DISPLACEMENT
        ASL     R1              ;MULTIPLY BY 8
        ASL     R1
        ASL     R1
        MOV     144,R0          ;DIVIDE BY 100 TO
CALCULATE INCHES
        JSR     PC,DIV
        MOV     R0,@ FRACT      ;HAS THE FRACTIONAL PART
        MOV     14,R0
        JSR     PC,DIV           ;DIVIDE BY 12 TO FIND
FEET AND INCHES
        MOV     R0,@ INCH
        MOV     R1,R0            ;OUTPUT THE NUMBER OF
FEET
        JSR     PC,ONUM3
        MOV     NFEET,R0        ;' FT. '
        JSR     PC,OUTPUT
        MOV     @ INCH,R0        ;OUTPUT THE NUMBER OF
INCHES
        JSR     PC,ONUM3
        MOV     DPT,R0          ;'.'
        JSR     PC,OUTPUT
        MOV     @ FRACT,R0       ;OUTPUT THE FRACTIONAL
PART
        JSR     PC,ONUM3
        MOV     NINCH,R0        ;' INCHES, ANGLE='
        JSR     PC,OUTPUT
        MOV     @ SAVE2,R1       ;CALCULATE THE ANGLE
```

```
        MOV     100,R0          ;DIVIDE BY 64
        JSR     PC,DIV
        MOV     R1,@ ANG        ;HAVE INTEGER PART IN
ANG
        MOV     144,R1          ;CALCULATE FRACTIONAL
PART OF ANGLE
        JSR     PC,MUL          ;MULTIPLY BY 100
        MOV     100,R0          ;DIVIDE BY 64
        JSR     PC,DIV
        MOV     R1,@ FRACT      ;HAVE FRACTIONAL PART
        MOV     @ ANG,R0        ;OUTPUT INTEGER PART
        JSR     PC,ONUM3
        MOV     DPT,R0         ;'.'
        JSR     PC,OUTPUT
        MOV     @ FRACT,R0      ;OUTPUT FRACTIONAL PART
        JSR     PC,ONUM3
        RTS     PC
;
;CLEAN  -THIS SUBROUTINE WILL CLEAR THE MEMORY
LOCATIONS
;        WHICH CORRESPOND TO THE PORTION OF THE DISPLAY
;        BELOW THE BACKWALL.  IT IS NOT NECESSARY TO
DISPLAY
;        THIS INFORMATION BECAUSE IT CORRESPONDS TO THE
;        CENTER BORE OF THE BILLET, AND BESIDES IT
MAKES
;        THE DISPLAY LOOK MESSY. THIS IS HOW THE
REGISTERS
;        ARE USED      R0: PIXEL POINTER
;                      R1: FIRST ADDRESS TO BE CLEARED
;                      R2: POINTER TO TOP OF NEXT COLUMN
;                      R3: COLUMN COUNTER
;                      ROW2: BOTTOM OF BACKWALL
CLEAN:   MOV     200,R3         ;COLUMN COUNTER
 MOV     60000,R0       ;START ADDRESS
 MOV     R0,R2
 ADD     400,R2         ;COMPUTE TOP OF NEXT COLUMN
 ADD     @ ROW2,R0      ;COMPUTE FIRST ADD TO BE
CLEARED
 TST     (R0)+          ;INC BY 2
 BIC     1,R0           ;MAKE ADDRESS A WORD BNDRY
 MOV     R0,R1
CLEANA:  CLR     (R1)+
 CMP     R1,R2          ;TOP OF NEXT COLUMN?
 BNE     CLEANA
 ADD     400,R2         ;NEXT COLUMN
 ADD     400,R0
 MOV     R0,R1
 SOB     R3,CLEANA
 RTS     PC
;
;MUL -THIS SECTION CALCULATES:  R0*R1->R0,R1
;    MULTIPLIES TWO SIXTEEN BIT NUMBERS IN R0 AND R1,
```

```
AND
;     FORMS A THIRTY-TWO BIT RESULT. RO HAS THE UPPER
WORD.
;
MUL:    MOV     RO,@ TEMPM
        CLR     RO
        MOV     R2,-(SP)
        MOV      21,R2
MULTL:  CLC
        ROR     RO
        ROR     R1
        BCC     MULT1
        ADD     @ TEMPM,RO
MULT1:  SOB     R2,MULTL
        MOV     (SP)+,R2
        RTS     PC
;
;DIV - THIS ROUTINE CALCULATES R1/RO
;       SIXTEEN BIT DIVISION.
;        R1 HAS THE QUOTIENT
;        RO THE REMAINDER.
;
DIV:    MOV     RO,@ TEMPM
        CLR     RO
        MOV     R2,-(SP)
        MOV      20,R2
DIVL:   CLC
        ROL     R1
        ROL     RO
        CMP     @ TEMPM,RO
        BHI     DIV1
        BIS      1,R1
        SUB     @ TEMPM,RO
DIV1:   SOB     R2,DIVL
        MOV     (SP)+,R2
        RTS     PC
;
;HOME - THIS SECTION MOVES ARRAY ALL THE WAY TO THE
RIGHT
;        SO THAT A FULL SCAN OF THE BILLET CAN BE DONE.
;HOMEA - USED AS A SUBSECTION TO MOVE ARRAY ALL THE
;         WAY RIGHT WITHOUT CHANGING PARAMETERS.
;
HOME:   MOV      7000,@ XLOC      ;SET XLOC SO MOTOR
WILL MOVE
        CLR     @ NFLAWS          ;NUMBER OF FLAWS =0
        CLR     @ MFLAG           ;NOT MOTOR SENSITIVE
        CLR     @ DISP            ;CLEAR DISPLACEMENT
HOMEA:  MOV     @ MRDBUF,RO       ;RIGHT SWITCH HIT?
        BIC     @ MRIGHT,RO
        BNE     HOMED             ;YES RETURN
        MOV      0,@ DIR          ;SET DIRECTION RIGHT
        CMP     @ XLOC,@ DISP
```

```
        BEQ     HOMED
        MOV      10000,R1          ;KILL TIME
HOME2:  MOV     @ MRDBUF,RO        ; AND LOOK FOR A
        BIC     @ MRIGHT,RO         ;  RIGHT SWITCH TO
BE PRESSED
        BNE     HOMED
        DEC     R1
        BNE     HOME2
        MOV      1,R1              ;MOVE ARRAY AGAIN
        JSR     PC,MOTOR
        BR      HOMEA
HOMED:  RTS     PC
;
;GETLAR -THIS ROUTINE GETS THE DISPLACEMENT AND  LENGTH
OF THE BILLET.
;        IT ALSO CALCULATES THE D ANGLE PER CLOCK PULSE
;        AND THE NUMBER OF CLOCK PULSES/REV.
;
GETLAR: MOV      77777,@ MAXX
        MOV      WIPE,RO          ;CLEAR PART OF SCREEN
        JSR     PC,OUTPUT
        MOV      OFFSET,RO        ;'ENTER DISPLACEMENT'
        JSR     PC,OUTPUT
        CLR     R3               ;SET UP R3 FOR POSSIBLE
RETURN
        JSR     PC,INNUM           ;GET RESPONSE
        TST     R3               ;CHECK FOR A RETURN OR
ZERO ENTERED
        BEQ     ILLEN
        CMP     R3, 216.         ;CHECK FOR LEGAL
DISPLACEMENT
        BGT     GETLAR
        INC     @ DIR
        MOV     R3,RO             ;CALCULATE
 PULSES=12.7* INCHES
        MOV      177,R1
        JSR     PC,MUL
        MOV      12,RO
        JSR     PC,DIV
        MOV     R1,@ DISP
        MOV     R1,R2
GETMOV: CMP     R2, 100           ;NUMBER OF DIFFERENCE
COUNTS > 64
        BGT     GMOV1            ;YES
        MOV     R2,R1             ;NO SEND THE REMAINING
DIFFERENCE
        JSR     PC,MOTOR          ;SEND THE COUNT
        CLR     R2                ;SET R2 TO DONE
CONDITION
        BR      GMOV2
GMOV1:  MOV      100,R1           ;MOVE BY 64 COUNTS
        JSR     PC,MOTOR
        SUB      100,R2           ;DEC DIFF COUNT BY 64
```

```
GMOV2:  TST     R2                  ;AT X POSITION?
        BNE     GETMOV              ;NO
ILLEN:  MOV      LENMES,RO          ;'ENTER BILLET LENGTH'
        JSR     PC,OUTPUT
        CLR     R3                  ;GET RESPONSE
        JSR     PC,INNUM
        TST     R3
        BEQ     ILLEN
        CMP     R3, 22              ;LENGTH <= 18
        BGT     ILLEN               ;NO PRINT MESSAGE
        MOV     R3,RO               ;CALCULATE MAX COUNT
        MOV      230,R1
        JSR     PC,MUL
        ADD     @ DISP,R1
        SUB      62,R1              ;SUBTRACT OFF 4
INCHES
        CMP     R1, 2692.           ;TOTAL MUST BE 18 FT.
OR LESS
        BGT     ILLEN
        MOV     R1,@ MAXX
        MOV     @ DISP,@ XLOC
;
;CALCULATE DANGLE/CLOCK PULSE AND NUMBER TICKS/REV
; DO IT OVER FIVE ROTATIONS OF THE BILLET.
; NTICKS HAS THE NUMBER OF TICKS (INTERRUPTS).
; NUMTIK WILL HAVE THE NUMBER OF TICKS FOR ONE
ROTATION.
;
 MOV        MESS1,RO        ;LOCATION OF MESS ->RO
 JSR       PC,OUTPUT        ;OUTPUT TO CRT
        MOV      5,R3
        JSR     PC,JIGGLE           ;ALIGN NTICKS WITH CAM
SW
        CLR     @ NTICKS
GET1:   JSR     PC,JIGGLE
        SOB     R3,GET1
        MOV     @ NTICKS,R1         ;CALCULATE NUMTIK
        MOV      5,RO
        JSR     PC,DIV
        MOV     R1,@ NUMTIK
        MOV     R1,RO               ;CALCULATE DANGLE
        MOV      23040.,R1           ;360/NUMTIK
;NOTE ANGLES ARE REPRESENTED 64 TIMES GREATER.
        JSR     PC,DIV
        MOV     R1,@ DANGLE
GETD:   RTS     PC
;
;CLKTIC - THIS IS THE INTERRUPT HANDLER FOR THE LINE
CLOCK
;          IT KEEPS TRACK OF THE BILLETS CURRENT
POSITION
;          AND IS USED TO TIME THE BILLET'S ROTATION.
;      NOTE: BILLET'S ANGLE IS SIXTY-FOUR TIMES GREATER
```

```
;            THAN IT ACTUALLY IS.  THIS IS TO ALLOW
;            FOR FINER ACCURACY WITHOUT FLOATING POINT
NUMBERS.
;
CLKTIC: INC     @ NTICKS            ;ADD ONE TO THE
NUMBER OF TICKS
        ADD     @ DANGLE,@ CANGLE   ;UP DATE THE BILLETS
ANGLE
        CMP      23040.,@ CANGLE     ; BILLETS ANGLE
>360
        BGT     CLK1                ;NO
        SUB      23040.,@ CANGLE     ;SUBTRACT OFF 360
CLK1:   RTI
;
; DLOG - THIS SECTION DISPLAYS  THE FLAW LOG.
;        FLAWS ARE DISPLAYED 22 AT A TIME.  AFTER
;        THE CURRENT 22 HAVE BEEN DISPLAYED, THE
;        PROGRAM WAITS FOR THE OPERATOR TO PRESS
;        A KEY. HITTING 'S' OR WHEN THE PROGRAM HAS
;        DISPLAYED ALL THE FLAWS, WILL RESULT IN
;        'THE FLAW LOG DISPLAYED' MESSAGE AND THE
;        PROGRAM WILL WAIT AGAIN FOR A KEY PRESS
;        BEFORE RETURNING TO THE MAIN PROGRAM.
;
DLOG:   TSTB    @ TTXCSR            ;CLEAR THE SCREEN
        BPL     DLOG
        MOVB     CLRSCN,@ TTXBUF
        MOV     @ NFLAWS,@ TEMP     ;CALCULATE THE NUMBER
OF FLAWS
        ASR     @ TEMP              ;NFLAWS HAS 4 TIMES
THE NUMBER
        ASR     @ TEMP
        MOV      1,@ LCOUNT         ;THIS IS FLAW NUMBER
COUNTER
        CLR     R5                  ;FLAW LOG POINTER
DLOG1:  MOV      26,@ COUNT         ;PRINT OUT 22 LINES
PER SCREEN
DLOG2:  TST     @ TEMP
        BEQ     DLOGD
        MOV      LFCR,R0          ;SEND LINE FEED AND CR
        JSR     PC,OUTPUT
        MOV     @ LCOUNT,R0         ;OUTPUT THE FLAW NUMBER
        INC     @ LCOUNT
        JSR     PC,ONUM3
        MOV      DPTB,R0            ;'. '
        JSR     PC,OUTPUT
        MOV     FLOG(R5),R1
        INC     R5
        INC     R5
        MOV     FLOG(R5),R2
        INC     R5
        INC     R5
        JSR     PC,DPOSA            ;DISPLAY POSITION
```

```
        DEC     @ TEMP              ;DEC COUNTERS
        DEC     @ COUNT             ;DISPLAYED 23?
        BNE     DLOG2               ; NO GO DO ANOTHER ONE
        MOV      DLM,RO            ;'PRESS <S> TO STOP
        JSR     PC,OUTPUT           ; OR ANY KEY TO
CONTINUE'
DLOG3:  TSTB    @ TRDCSR            ;WAIT FOR A KEY STROKE
        BPL     DLOG3
        MOVB    @ TRDBUF,R1         ;GET RESPONSE
        BIC      17600,R1           ;CLEAR UPPER BYTE
        CMPB    R1, 123             ;'S' PRESSED?
        BNE     DLOG1               ; NO CONTINUE
DISPLAYING LOG
DLOGD:  MOV      DLOGM,RO          ;'LF,CR LOG DISPLAYED
PRESS KEY TO EXIT'
        JSR     PC,OUTPUT
DLOG4:  TSTB    @ TRDCSR            ;WAIT FOR KEY PRESS
        BPL     DLOG4
        JMP     COMMN2
;
; JIGGLE- THIS SECTION JIGGLES MOTOR LEFT AND THEN
RIGHT
;           SO THAT DETECTION OF THE CAM SWITCH IS
POSSIBLE
;           THIS SECTION RETURNS WHEN THE CAM SWITCH HAS
;           TOGGLED.  THIS IS USED TO TIME THE BILLET AND
;           ALSO TO RESET THE BILLET.
;
JIGGLE: CLR     R5                  ;R5 IS USED AS SWITCH
FLAG
        MOV      177,@ MTXBUF      ;MOVE LEFT AND RESET CAM
        MOV     @ MRDBUF,RO        ;GET OLD DONE BIT STATUS
        BIC     @ MDONEB,RO
J1A:    MOV     @ MRDBUF,R1        ;WAIT FOR DONE TO GO 1
TO 0
        BIC     @ MDONEB,R1
        CMP     RO,R1
        BEQ     J1A
J1B:    MOV     @ MRDBUF,R1        ;WAIT FOR DONE BIT TO
GOTO 1
        BIC     @ MDONEB,R1
        BEQ     J1B
        MOV      177777,RO             ;KILL SOME TIME
JO:     DEC     RO
        BNE     JO
        MOV      376,@ MTXBUF      ;MOVE MOTOR BACK RIGHT
ENABLE CAM SWITCH
        MOV     @ MRDBUF,RO        ;GET OLD DONE BIT STATUS
        BIC     @ MDONEB,RO
J3A:    MOV     @ MRDBUF,R1        ;WAIT FOR DONE TO GO 1
TO 0
        BIC     @ MDONEB,R1
        CMP     RO,R1
```

```
        BEQ     J3A
J3:     MOV     @ MRDBUF,RO       ;GET STATUS BITS
        MOV     RO,R1
        BIC     @ MCAM,R1         ;CAM SET?
        BEQ     J4                ;NO
        MOV      1,R5             ;YES SET FLAG
J4:     BIC     @ MDONEB,RO       ;MOTOR DONE?
        BEQ     J3                ;NO CONTINUE TO CHECK
        TST     R5                ;CAM SWITCH HIT
        BEQ     KEY                ;NO WAIT FOR SET
        CLR     @ CANGLE          ;RESET CURRENT ANGLE
        RTS     PC                ;YES RETURN
KEY:     TST      @ KFLAG
 BEQ     J3
 TSTB    @ TRDCSR
 BPL     J3
 JMP     LOCA21
;
;
; MOTOR - THIS ROUTINE HANDLES MOST OF THE INTERACTION
;           BETWEEN THE MOTOR AND THE REST OF THE
PROGRAMS
;           R1 HAS THE NUMBER OF PULSES
;       ****NOTE:THE ACTUAL NUMBER OF PULSES SENT IS
R1*128
;                 THE DIFFERENCE IS DUE TO THE HALF STEP
IS
;                 USED ON THE STEPPER MOTOR.
;           DIR HAS THE DIRECTION TO MOVE THE ARRAY ( 0
-RIGHT 1 -LEFT)
;           MFLAG INDICATES WHETHER THE MOVE REQUEST IS
;                 SENSITIVE TO THE PROGRAM. (0 -NO
1-YES).
;                 IF YES THEN A MESSAGE WILL BE PRINTED
IF
;                 A SWITCH OR BOUNDARY WAS REACHED. IF NO
THEN
;                 THE MOVE REQUEST IS IGNORED.
;
;       REVISION AUG 09, 1983 BY RICHARD L. UNDERWOOD
;
;       DUE TO THE CHANGES IN THE INTERFACE BOARD TO THE
STEPPER MOTOR
;       CONTROLLER, THE ROUTINE MOTOR WAS REVISED AS
FOLLOWS:
;
;   1) THE ORIGINAL ROUTINE SENT ONE PULSE TO THE
INTERFACE BOARD
;       WHICH REPRESENTED 0.079 INCHES ALONG THE X AXIS.
THE
;       HARDWARE NOW SENT ONLY ONE PULSE WHICH IS ONLY
0.0005 INCH
;       ALONG THE X AXIS. TO COMPENSATE FOR THIS THE
```

```
COUNTS ARE MULTIPLIED
;       BY 158.
;
;   2) IT IS POSSIBLE THAT THE NUMBER OF COUNTS WHEN
MULTIPLIED BY
;       158 WILL EXCEED THE STORAGE CAPABILITY OF A 16
BIT WORD.
;       THEREFORE, WE MOVE IN MAXIMUM GROUPS OF 200 *
158.
;       THE SECTION "CYCLE" WILL CHECK TO SEE THE NUMBER
OF REMAINING
;       COUNTS AND TAKE APPROPRIATE ACTION.
;
;   3) THE SECTION THAT WAITS FOR THE BOARD TO ACCEPT
THE COUNTS
;       WAS DELETED BECAUSE WE SEND ONLY ONE COUNT AT A
TIME.
;
;   4) THE EXIT POINT OF "MOTOR" WAS MOVED.
;
;   5) THE RAMP WAS ADJUSTED SO AS TO WORK PROPERLY.
;
;
MOTOR:  MOV     R1,TCOUNT     ; STORE COUNTS
        TST     @ DIR           ;WHICH DIRECTION?
        BEQ     MOTRT           ;RIGHT
        MOV     @ MRDBUF,RO     ;LEFT, CHECK LEFT SWITCH
        BIC     @ MLEFT,RO
        BNE     BNDRY           ;ARRAY REACHED LEFT SIDE
        MOV     @ XLOC,RO       ;CHECK TO SEE IF MOTOR
        ADD     R1,RO           ; WOULD MOVE PASSED END
        CMP     RO,@ MAXX
        BGT     BNDRY           ;YES DONE MOVING MOTOR
        MOV     RO,@ XLOC
        BR      CYCLE
MOTRT:  MOV     @ MRDBUF,RO     ;MOVE ARRAY RIGHT -CHECK
RIGHT SWITCH
        BIC     @ MRIGHT,RO
        BNE     BNDRY           ;ARRAY REACHED RIGHT SIDE
        MOV     @ XLOC,RO       ;CHECK TO SEE IF ARRAY
WOULD
        SUB     R1,RO           ;BE MOVED OUT OF BOUNDS
        CMP     RO,@ DISP
        BLT     BNDRY           ;YES DON'T MOVE MOTOR
        MOV     RO,@ XLOC
CYCLE:  MOV     TCOUNT,R1     ;GET COUNTS TO MOVE
        CLR     FFLAG         ; SET FLAG FOR ONLY ONE MOVE
        CMP     R1, 310         ;FFLAG IS O IF R1 <= 200
        BLE     MOT1
        DEC     FFLAG         ;FFLAG IS -1 IF R1 > 200
        MOV      310,R1         ;SET UP FOR 200 COUNT MOVE
        SUB     R1,TCOUNT     ;SUBT 200 FROM TCOUNT
MOT1:   MOV     @ SPEED,@ TEMP
```

```
        MOV     407,R0
        JSR     PC,MUL          ;MULTIPLY BY 263 TO MOVE
.079 IN
        MOV     R1,@ TEMPC
        MOV      1,@ SLINC
        MOV     @ NSTEPS,@ TEMPM    ;NUMBER OF REAL HALF
COUNTS IN RAMP UP
        SUB     @ NSTEPS,@ TEMPC    ;SUBTRACT OFF COUNTS
IN RAMP UP FROM TOTAL
        JSR     PC,MRAMPL           ;RAMP UP
;************ NOW GO OVER
***********************************
        MOV     @ TEMPC,R1
        SUB     @ NSTEPS,R1         ;SUBTRACT OFF COUNTS
FOR RAMP DOWN
        MOV     R1,@ TEMPM
        MOV     @ FSPEED,@ TEMP
        JSR     PC,MRAMPL
;*********** NOW RAMP DOWN
*********************************
        CLR     @ SLINC
        MOV     @ NSTEPS,@ TEMPM
        JSR     PC,MRAMPL
        TST     FFLAG
        BNE     CYCLE               ;-1,DO ANOTHER CYCLE
MOTDUN: RTS     PC                  ;0, RETURN FROM MOTOR
HERE
;********** THIS SECTION DOES THE ACTUAL MOVE
**************
MRAMPL: MOV      176,R1
        ADD     @ DIR,R1        ;PUT IN DIRECTION BIT
        MOVB    R1,@ MTXBUF     ;SEND THE PATTERN
; KILL SOME TIME TO FORM RAMP
        MOV     @ TEMP,R0
PAUSE:  DEC     R0
        BNE     PAUSE
        MOV      4,R0
        TST     @ SLINC         ; IF SLINC =1 THEN
        BEQ     MOT7            ; RAMP DELAY =DELAY - 4
        SUB     R0,@ TEMP       ; OR FSPEED WHICH EVER IS
LARGER
        CMP     @ TEMP,@ FSPEED
        BHIS    MOT6
        MOV     @ FSPEED,@ TEMP
MOT6:   DEC     @ TEMPM
        BNE     MRAMPL
        RTS     PC
MOT7:   CMP     R0,@ SPEED
        BHIS    MOT8
        ADD     R0,@ TEMP
        BR      MOT6
MOT8:   MOV     @ SPEED,@ TEMP
        BR      MOT6
```

```
;***********************************
; MOTOR MOVEMENT CONSTANTS
FSPEED: .WORD  60      ;THIS CONTROLS THE HIGHEST RATE
TO SEND PULSES
SPEED:  .WORD  460     ;THIS CONTROLS THE SLOWEST RATE
TO SENT PULSES
NSTEPS: .WORD  100    ;THIS IS THE NUMBER OF STEPS IN
THE RAMP UP/DOWN
FFLAG:  .WORD          ;FLAG FOR LAST CYCLE ZERO = LAST
CYCLE
TCOUNT: .WORD          ;STORAGE FOR COUNTS TO MOVE
;***********************************
;
; A SWITCH OR BOUNDARY REACHED IF MFLAG =1 THEN THE
CONDITION
; WAS UNEXPECTED AND A MESSAGE IS TO BE PRINTED. THE
PROGRAM
; RETURNS CONTROL TO THE CALLING ROUTINE AFTER A SWITCH
IS PRESSED.
; IF MFLAG=0 THEN THE CONDITION WASN'T UNEXPECTED, I.E.
HOME
; ROUTINE WANTS THE LEFT SWITCH HIT, SO ROUTINE IGNORES
REQUEST.
;
BNDRY:  TST     @ MFLAG         ;MOTOR SENSITIVE?
        BEQ     MOTDUN          ;NO RETURN
        MOV      MMB,RO        ;CANT MOVE MESSAGE
        JSR     PC,OUTPUT       ;SEND THE MESSAGE
MWAIT1: TSTB    @ TRDCSR        ;WAIT FOR A KEY TO BE
PRESSED
        BPL     MWAIT1
        MOV     @ TRDBUF,RO     ;READ DUMMY KEY
        MOV      MMC,RO        ;CLEAR MESSAGE
        JMP     OUTPUT          ;GOTO TO OUTPUT THERE RTS
RETURNS
;
; POWERU - PRINTS INSTRUCTIONS FOR POWER UP
;          AND THEN WAITS FOR A KEY TO BE PRESSED.
;
POWERU: MOV      PMESSU,RO
        JSR     PC,OUTPUT
POWL:   TSTB    @ TRDCSR
        BPL     POWL
        MOV     @ TRDBUF,R1
        RTS     PC
; POWERD - PRINTS INSTRUCTIONS FOR POWER DOWN
;          AND THEN WAITS FOR A KEY TO BE PRESSED.
POWERD: MOV      PMSSD,RO
        JSR     PC,OUTPUT
        BR      POWL
;
; SECTION XO. VARIABLES FOR MOVEMENT AND LOGGING
ROUTINES
```

```
;
CFLAG=32402  ;TELLS WHETHER TO DO A COMPLETE FLAW CHECK
CANGLE=32404 ;CURRENT ANGLE OF BILLET
NUMTIK=32406 ;NUMBER OF LINE CLOCK PULSES IN ONE REV.
DANGLE=32410 ;CHANGE IN ANGLE PER LINE CLOCK PULSE
KFLAG=32412  ;SHOULD KEYBOARD BE SENSITIVE TO ARRAY
MOVE
             ; INSTRUCTIONS WHILE IN JIGGLE
XLOC=32416   ;CURRENT X OF ARRAY LOCATION IN COUNTS
MAXX=32420   ;MAX X POSITION THE ARRAY CAN MOVE
MRIGHT: .WORD   177775 ;THESE ARE THE BIT MASKS FOR
SWITCHES
MCAM:   .WORD   177757
MDONEB: .WORD   177773
MLEFT:  .WORD   177767
NFLAWS=32422 ;NUMBER OF FLAWS FOUND*4
NTICKS=32424 ;NUMBER OF TICKS
COUNT=32426  ;COUNTERS AND TEMPORARY LOCATIONS USED FOR
CALCULATIONS
LCOUNT=32430
TEMP=32432
TEMPM=32434
INCH=32436
FRACT=32440
ANG=32442
TPOSX=32444  ;TARGET X POSITION FOR LOCATE
TANGLE=32446 ;TARGET ANGLE FOR LOCATE
DIR=32450    ;DIRECTION FLAG FOR MOTOR =1 LEFT 0 RIGHT
MFLAG=32452  ;MOTOR SENSITIVE FLAG
NFLAG=32454  ;NUMBER OUTPUT FLAG
DISP=32460   ;DISPLACEMENT
PICT=32462   ;PICTURE FLAG
SAVE2=32464  ;USED TO SAVE PARAMETERS
SLINC=32466  ;SLOPE FOR RAMP UP AND DOWN
TEMPC=32500  ;TEMP COUNT
FLOG=33000        ;THIS IS THE FLAW LOG DON'T PUT
ANYTHING 33000->37760
                  ;FLAWS ARE LOGGED BY LOCATION IN
COUNTS AND ANGLE
                  ;1 WORD FOR EACH PARAMETER
; SECTION X1. VARIABLE NAMES/ MEMORY ALLOCATIONS
PSTACK=20776    ;PROGRAM STACK
CSRBUF=30000    ;BUFFER FOR ICSR
BUSENB=30000    ;WRITE ENB(1); Q-BUS/D-BUS(0)
INTENB=30001    ;DISPLAY ENB(15); INTERRUPT ENB(8)
SRDLY=30002     ;SAMPLING RATE AND DELAY
DELAY=30002     ;DELAY
SRATE=30003     ;SAMPLING RATE
RAMPS=30004     ;RAMP GAINS: NEAR,FAR,SLOPE
GAINS=30004     ;NEAR,FAR RAMP GAINS
SLOPE=30005     ;SLOPE OF RAMP GAINS
GBUF=30006      ;TXGAIN AND RXATTN
TXGAIN=30006    ;TRANSMIT GAIN
```

```
RXATTN=30007        ;RECEIVER ATTENUATION
CMDCHR=30010        ;USER COMMAND CHARACTER
PIXEL=30012         ;SINGLE PIXEL BUFFER
TEMP1=30014         ;TEMPORARY RESTING PLACE
TEMP2=30016         ;TEMPORARY RESTING PLACE
FLAG1=30020         ;FLAW DETECTED?
FLAG2=30022
FRAMEA=30024        ;CONTROLS Q-BUS/D-BUS CONNECTION OF
FRAMES:
                              ;    0 -- FRAME0 ON Q-BUS;
FRAME1 ON D-BUS
                              ;    1 -- FRAME0 ON D-BUS;
FRAME1 ON Q-BUS
FRAMEB=30026        ;SAME FUNCTION AS FRAMEA
NOISE=30030         ;NOISE SETTING
SHADOW=30032        ;SHADOW DETECTION SETTING
FLAG4=30034
NOISE2=30036
ROW1=30040          ;PLACE TO STORE ROW NUMBERS
ROW2=30042
ROW3=30044
WIDTH=30046
NUMBUF=30050        ;DON'T PUT ANYTHING FROM 30050 TO
30057!!
ALPHA=30060         ;DON'T PUT ANYTHING FROM 30060 TO
30160!!
QBUS=30200
DBUS=30202
AVE=30210           ;USED IN FLAW DETECTION
MIN=30212           ;USED IN FLAW DETECTION
HOLD1=30214
VRANGE=30220
HRANGE=30222
RSIDE=30224
LSIDE=30226
MANUAL=30230        ;MANUAL CONTROL FLAG
BACKWL=31000        ;DON'T PUT ANYTHING FROM 31000 TO
31377!!
SMTHBW=31400        ;DON'T PUT ANYTHING FROM 31400 TO
31777!!
BORDRS=32000        ;DON'T PUT ANYTHING FROM 32000 TO
32400!!
; SECTION X2. INTERFACE REGISTERS
ICSR=160000         ;IMAGER INTERFACE
ISRDLY=160002
IRAMPS=160004
IGAINS=160006
MRDCSR=176500       ;MOTOR INTERFACE
MRDBUF=176502
MTXCSR=176504
MTXBUF=176506
TRDCSR=177560       ;TERMINAL INTERFACE
TRDBUF=177562
```

```
TTXCSR=177564
TTXBUF=177566
; SECTION X3. INTERRUPT VECTORS
STRTPC=24       ;POWER UP PC
STRTPS=26       ;POWER UP PS
PRSTHV=200      ;INTERRUPT FROM PROBE RESET
STEPRV=300      ;INTERRUPT FROM STEPPER MOTOR
TERMRV=60       ;RECEIVE INTERRUPT FROM TERMINAL
TERMTV=64       ;TRANSMIT INTERRUPT TO TERMINAL
; SECTION X4. CONSTANTS
        BEEP=7
        CR=15
        LF=12
        CLRSCN=32
        SPACE=40
        LEFTP=50
        RIGHTP=51
        ESCAPE=33
        EQUALS=75
        BACKSP=10
; SECTION X5. SYSTEM MESSAGES
WIPE:   .BYTE   ESCAPE,EQUALS
        .ASCII  '!
'
        .BYTE   CR,LF
        .ASCIZ  '
'
MENU3:  .BYTE   CLRSCN,ESCAPE,EQUALS
        .ASCII  '$ '
        .ASCII  'EXTRA MENU COMMANDS:'
        .BYTE   CR,LF
        .ASCII  '(C) SINGLE SHOT FLAW DETECTION'
        .BYTE   CR,LF
        .ASCII  '(D) REPEATED FLAW DETECTION'
        .BYTE   CR,LF
        .ASCII  '(U) UPLOAD FRAME STORE'
        .BYTE   CR,LF
        .ASCII  '(Q) SYSTEM SHUT OFF'
        .BYTE   CR,LF
        .ASCII  '(F) EXIT TO FIRST MENU'
        .BYTE   CR,LF
        .ASCII  '(S) EXIT TO SECOND MENU'
        .BYTE   CR,LF
        .ASCII  '(H) MOVE MOTOR TO THE HOME POSITION'
        .BYTE   CR,LF
        .ASCIZ  ' ENTER COMMAND: '
CMESS1: .BYTE   CLRSCN,ESCAPE,EQUALS
        .ASCII  '$ '
        .ASCII  ' FIRST MENU COMMANDS:'
        .BYTE   CR,LF
        .ASCII  '(S) SET PARAMETERS '
        .BYTE   CR,LF
        .ASCII  '(P) ALIGN PROBE'
```

```
        .BYTE   CR,LF
        .ASCII  '(C) CLEAR FRAMESTORE'
        .BYTE   CR,LF
        .ASCII  '(D) CHANGE DISPLAYED FRAMESTORE'
        .BYTE   CR,LF
        .ASCII  '(F) FIND FLAWS'
        .BYTE   CR,LF
        .ASCII  '(Q) SYSTEM SHUT OFF'
        .BYTE   CR,LF
        .ASCII  '(M) EXTRA ROUTINES'
        .BYTE   CR,LF
        .ASCIZ  ' ENTER COMMAND: '
MENU2:    .BYTE   CLRSCN,ESCAPE,EQUALS
        .ASCII  '$ '
        .ASCII  ' SECOND MENU COMMANDS:'
        .BYTE   CR,LF
        .ASCII  '(S) SHOW FLAW LOG '
        .BYTE   CR,LF
        .ASCII  '(L) LOOK AT FLAWS '
        .BYTE   CR,LF
        .ASCII  '(C) CLEAR FRAMESTORE'
        .BYTE   CR,LF
        .ASCII  '(D) CHANGE DISPLAYED FRAMESTORE'
        .BYTE   CR,LF
        .ASCII  '(Q) SYSTEM SHUT OFF'
        .BYTE   CR,LF
        .ASCII  '(M) EXTRA ROUTINES'
        .BYTE   CR,LF
        .ASCIZ  '   ENTER COMMAND:'
EMESS1: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .BYTE   BEEP
        .ASCIZ  'ERROR -- BACKWALL NOT FOUND
'
CMESS2: .BYTE   CLRSCN,ESCAPE,EQUALS
        .ASCII  '! '
        .ASCII  'PARAMETER CHANGE ROUTINE'
        .BYTE   ESCAPE,EQUALS
        .ASCII  '$ '
        .ASCII  '   CHOOSE THE PARAMETER YOU WISH TO
OPEN'
        .BYTE   CR,LF
        .ASCII  '   OR EXIT THIS PROGRAM BY STRIKING
<CR>'
        .BYTE   CR,LF,LF
        .ASCII  'PARAMETERS:'
        .BYTE   CR,LF
        .ASCIZ  '(A) SAMPLING RATE'
CMESS3: .BYTE   CR,LF
        .ASCIZ  '(B) TRANSMIT GAIN'
CMESS4: .BYTE   CR,LF
        .ASCIZ  '(C) RECEIVER DELAY'
CMESS5: .BYTE   CR,LF
```

```
        .ASCIZ  '(D) NEAR RAMP GAIN'
CMESS7: .BYTE   CR,LF
        .ASCIZ  '(E) RAMP SLOPE'
CMESS8: .BYTE   CR,LF
        .ASCIZ  '(F) RECEIVER ATTENUATION'
CMESS9: .BYTE   CR,LF
        .ASCIZ  '(G) SYSTEM NOISE THRESHOLD'
CMESS0: .BYTE   CR,LF
        .ASCIZ  '(H) SHADOW DETECTION THRESHOLD'
PMESSA: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER SAMPLING RATE (1,2,3): '
PMESSB: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER TRANSMIT GAIN (-db FROM 0 TO
30): '
PMESSC: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER DESIRED DELAY (0 THRU 63): '
PMESSD: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER NEAR RAMP GAIN: '
PMESSF: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER RAMP SLOPE: '
PMESSG: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER ATTENUATION (0 OR 1): '
PMESSH: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER BACKGROUND NOISE THRESHOLD (0 TO
20): '
PMESSI: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'ENTER SHADOW DETECTION THRESHOLD: '
EMESS2: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .BYTE   BEEP
        .ASCIZ  'ERROR -- ILLEGAL ENTRY -- REENTER
COMMAND'
BMESS1: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'THE BACKWALL EXTENDS FROM ROW'
BMESS2: .BYTE   CR,LF
        .ASCIZ  '                   DOWN TO ROW'
DMESS1: .BYTE   ESCAPE,EQUALS
        .ASCII  '! '
        .ASCIZ  'FRAMESTORE'
DMESS2: .ASCII  ' IS CURRENTLY DISPLAYED'
        .BYTE   CR,LF
        .ASCIZ  'ENTER CHOICE FOR DISPLAY (0 OR 1): '
BMESS3: .BYTE   ESCAPE,EQUALS
        .ASCIZ  '!='
```

```
BMESS4: .BYTE   ESCAPE,EQUALS
        .BYTE   42,75,0
DINIT1: .BYTE   CLRSCN,ESCAPE,EQUALS
        .ASCIZ  '3 FRAMESTORE'
DINIT2: .ASCIZ  ' IS CURRENTLY DISPLAYED'
DMESS0: .BYTE   ESCAPE,EQUALS
        .ASCIZ  '3*'
FMESS1: .BYTE   ESCAPE,EQUALS
        .ASCIZ  '! NO FLAWS DETECTED             '
FMESS2: .BYTE   ESCAPE,EQUALS
        .ASCIZ  '! FLAW(S) DETECTED                '
LENMES: .BYTE   CLRSCN,CR,LF
        .ASCII  'ENTER BILLET LENGTH IN FEET (1 TO 18)
'
        .BYTE   CR,LF
        .ASCIZ  'NOTE: LENGTH + DISPLACEMENT CAN NOT BE
OVER 18 FT. '
MSCAN1: .BYTE   CR,LF
        .ASCIZ  'SCAN COMPLETE '
MSCAN2: .ASCIZ  'FLAWS FOUND.  PRESS A KEY TO EXIT'
LFCR:   .BYTE   CR,LF
        .ASCIZ  ' '
POSPRT: .BYTE   ESCAPE,EQUALS
        .ASCII  '!'
        .BYTE   CR,LF
        .ASCIZ  ' CURRENT POSITION IS '
DPT:    .ASCIZ  '.'
DPTB:   .ASCIZ  '. '
NFEET:  .ASCIZ  ' FT. '
NINCH:  .ASCIZ  ' INCHES, ANGLE='
DLOGM:   BYTE   CR,LF
        .BYTE   BEEP
        .ASCIZ  'FLAW LOG DISPLAYED PRESS KEY TO EXIT'
LM1:    .BYTE   CR,LF
        .ASCIZ  'ENTER FLAW NUMBER OR <RETURN> TO EXIT'
LM2:    .BYTE   CR,LF
        .BYTE   BEEP
        .ASCIZ  'ILLEGAL FLAW NUMBER ENTERED'
MMB:    .BYTE   BEEP,ESCAPE,EQUALS
        .ASCIZ  '3 ARRAY REACHED A BOUNDARY-MOVE
IGNORED. PRESS A KEY'
MMC:    .BYTE   BEEP,ESCAPE,EQUALS
        .ASCIZ  '3
'
DLM:    .BYTE   CR,LF
        .ASCII  'PRESS <S> TO STOP'
        .BYTE   CR,LF
        .ASCIZ  'OR ANY OTHER KEY TO CONTINUE'
FMESS3: .BYTE   CR,LF
        .BYTE   BEEP
        .ASCII  'TOO MANY FLAWS DETECTED'
        .BYTE   CR,LF
        .ASCIZ  'FLAW LOG FULL'
```

```
LM3:     .BYTE   CLRSCN,CR,LF,LF,LF
         .ASCII  'LOCATE MOVEMENT INSTRUCTIONS:'
         .BYTE   CR,LF
         .ASCII  '(S) DO ANOTHER OR EXIT'
         .BYTE   CR,LF
         .ASCII  '(H) TO MOVE LEFT'
         .BYTE   CR,LF
         .ASCII  '(L) TO MOVE RIGHT'
         .BYTE   CR,LF
         .ASCII  '(K) TO MOVE UP'
         .BYTE   CR,LF
         .ASCII  '(J) TO MOVE DOWN'
         .BYTE   CR,LF
         .ASCIZ  '(P) DISPLAY PRESENT LOCATION'
MESS1:    .BYTE   CLRSCN,CR,LF
 .ASCIZ  'FIVE ROTATIONS OF THE BILLET ARE BEING TIMED'
PMESSU:  .BYTE   CLRSCN,CR,LF
         .ASCII  'INSTRUCTIONS FOR SYSTEM POWER UP'
         .BYTE   CR,LF
         .ASCII  '1 -CONNECT TV AND STEPPER CABLES'
         .BYTE   CR,LF
         .ASCII  '2 -POWER UP TV AND STEPPER MOTOR'
         .BYTE   CR,LF
         .ASCII  '3 -TURN ON SWITCH ON FRONT OF STAND'
         .BYTE   CR,LF
         .ASCIZ  'PRESS A KEY WHEN COMPLETE'
PMSSD:   .BYTE   CLRSCN,CR,LF
         .ASCII  'INSTRUCTIONS FOR SYSTEM POWER DOWN'
         .BYTE   CR,LF
         .ASCII  '1 -TURN OFF TV UNIT AND STEPPER MOTOR'
         .BYTE   CR,LF
         .ASCII  '2 -TURN OFF SWITCH ON THE BACK OF THE
STAND'
         .BYTE   CR,LF
         .ASCII  '3 -DISCONNECT STEPPER MOTOR AND TV
CABLES'
         .BYTE   CR,LF
         .ASCII  '4 -TURN OFF SWITCH ON FRONT OF THE
STAND'
         .ASCIZ  ' PRESS ANY KEY TO EXIT '
OFFSET:  .BYTE   CLRSCN,CR,LF
         .ASCIZ  ' ENTER DISPLACEMENT IN INCHES (0 TO
216) '
ILNUM:   .BYTE   BEEP,CR,LF
         .ASCIZ  ' ILLEGAL DIGIT OR CHARACTER ENTERED.
TRY AGAIN '
TERM:    .BYTE   0,0,0
         .END
```

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